The Coming Age of Solar Energy

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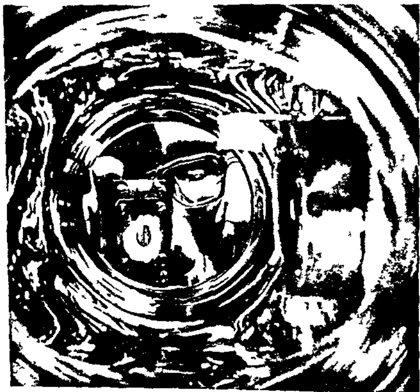
by D S Halacy, Jr



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Contents

Introduction

I make no pretense of having invented solar energy as some of my friends jokingly claim Indeed it was only in 1955 at Phoenix s World Symposium that I discovered the stuff Since then I have listened to solar-powered radios drunk solar distilled water, and eaten solar-cooked steaks I have also become increasingly convinced that the day is nearing when we will do far more with this energy than power our satellite and space vehicle equipment

While I am indebted to many people for much help with the book I hereby release them from any responsibility for the errors that may remain confident that these will be details not affecting the validity of the premise in the title I also assume full responsibility for the optimistic predictions since scientists and even engineers are cautious by nature and training

In rereading these pages I note occasional repetition of ideas or specific examples from chapter to chapter, but I make no apology for such redundancy Without it individual chapters would not be complete in themselves and more importantly certain ideas would not have been underscored sufficiently Perhaps for the book to communicate most efficiently you should read it the way I wrote it—with the sun in my eyes

D S Halacy, Jr
Glendale Arizona
May 1963

The Coming Age of Solar Energy

1

A Look at the Sun

"While the sunne shineth—make hay"
—*John Heywood, 1546*

For a long time before and since Heywood gave us this advice in his collection of proverbs, man has indeed made hay while the sun shone More recently science has even improved on nature with a commercial solar hay drier to do the job faster and better This solar hay drier, unfortunately is a kind of commentary, or small-scale model of what mankind in general has done with solar energy—little else *but* make hay

Our world is not noted for its conservation of anything, as its conspicuous consumption of power attests Yet the prodigal sun bombards us each day with about 32 000 times as much potential power as we are able to get rid of in twenty-four hours! It has been doing this since the dawn of our solar system and will likely continue its kindly performance for millions and perhaps billions of years of man s future For the maker of hay, at least, this beneficence is a never-

ending source of wonder The rest of us might well consider this primary source of energy that we call the sun, so that we can better understand what it is and its tremendous potential

Most of us are vaguely aware that our sun is actually a star, an orange dwarf at that, although the term is relative since the sun s mass is more than 330 000 times that of earth On this scale, if the earth weighed but an ounce the sun would tip the balance at about 30 tons We are principally aware of the sun because it shines This sunshine reaches across some 93 millions of miles of space in a bit over eight minutes because it is electromagnetic radiation and travels with the speed of light Most of this radiation occupies the spectrum from about ¼ micron to 3 microns or millionths of a meter A tiny amount of it lies in the extremely short, and invisible ultraviolet region, about half of it is the visible light we u e in seeing, the rest is infrared or long waves

Infrared rays account for the sun s heat We learn from experience that the sun will burn our backs if we are careless at the beach or even our fingers if we are clumsy in using a burning glass When we remember that this heat has come to us over such a magnificent distance and when we are told that earth and all eight of its sister planets together intercept only about ½₁₀₀ millionth of the total radiation, we realize that the sun is indeed a great ball of fire How hot we have only recently learned

Some two hundred years ago the astronomer Herschel suggested that although the surface of the sun was obviously quite hot inhabitants might live cosily inside it kept comfortably warm by the furnace above them We have since satisfied ourselves that this charmingly naive concept was gravely in error and that the inside of the sun is even hotter than its outside

The process of the fusion of hydrogen into helium

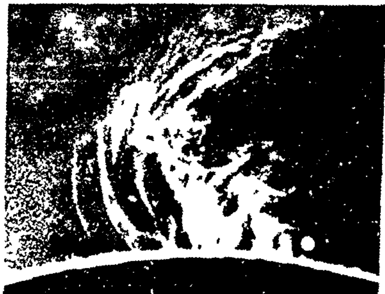
whereby the sun is continuously converting its matter into radiant energy, takes place at an estimated 30 million degrees This is far too hot to be called burning, or any other physical or chemical reaction we are familiar with Even the sun s corona is believed to reach about 2 million degrees Thus the surface, at 10 000 degrees or so is relatively cool, even though man can achieve such a temperature only with sophisticated techniques like those of electrical plasma generation the shock tube, and so on

Solar Energy Its Potential

As a result of the fusion inferno taking place in the sun, then, an appreciable amount of energy strikes the earth Of course this energy is not as great as that leaving the sun, having diminished during its 93-million mile trip by the law of inverse squares The 'solar constant,' the average amount of sun energy just above the earth s atmosphere, is called the 'langley,' and amounts to 451 Btu s per hour per square foot Translated into terms we can more readily visualize a square yard of area exposed to direct sunlight continuously receives nearly two horsepower from the sun!

This value is a maximum figure and is only approached atop high mountains or in very clear air Clouds, haze, dust, smog and fog cut the amount of energy received and London and Los Angeles are not likely candidates for solar energy installations However an acre of ground in the southern United States receives the equivalent of 4,000 horsepower under bright sun at noon and a quarter section of land is showered with energy equal to that delivered by an oil well producing 2 500 barrels of crude oil a day Closer home the solar energy beating wastefully down on our housetop amounts to perhaps a hundred times that coming in through conventional utility wires

To put these figures into better perspective, we can compare them with our present use of power from other sources Yearly in the United States we use, in addition to man and animal power, 8 trillion horsepower hours in mechanical devices It is indeed fortunate we do not have to stable such an amount of horseflesh But while we are burning up what



Mount Wilson Palomar Observatories

Solar prominences tower up from the sun s surface Their size is indicated by the white dot which is the dimension of earth

seems a mountain of energy the sun is sending us 12 000 trillion horsepower hours

Solar energy, then represents power and plenty of it It is free and it is everywhere and it requires no transportation or maintenance But to the man who now buys power conveniently for as little as a penny a kilowatt hour, what does solar energy represent but an interesting and amazing scien

tific curiosity? The answer is simple The end of our "fossil" fuels is in sight, and at the very time man is demanding power in increasingly large quantities The day is coming when we must look around for more sources of energy than coal oil and even nuclear energy

Our Energy Needs

A few hundred years ago man could satisfy his modest demands for energy with muscle power, either his own or that of helpers, slaves, or animals This muscle power he sometimes augmented with power from wood, wind, and water It is important to note that this is pretty much a current or day-to-day, use of solar energy, a living within our income from the sun Even when men spoiled the forests, a relatively few years would replenish them

Then man grew clever enough to discover he didn't have to live on income but could use the 'capital' energy nature had capriciously stored for him over millions of years The fossil fuels are so named because they are actually composed of long decayed plants and animals In them the energy of the sun, converted not too efficiently to hydrocarbons, has been stored safely through the ages When man began to burn coal and oil he found an easy way to get work done

At first he drew on these inherited fuels at a low enough rate so that his balance of power" remained favorable Even as late as 1850 he had used up only a small fraction of the capital energy stored in the ground By that time, eight and a half million Americans were using only about one-third horsepower apiece in mechanical equipment But man, ever smarter dug deeper into his wonderful bank By 1900 power consumption was closer to one horsepower per head and the heads had increased about eight times

Fortunately the population had only doubled again by

1950, because each man woman and child in the United States was then using more than thirty horsepower Thus, the general trend toward more use of power not only continued but accelerated greatly In the hundred years from 1850 to 1950 man used almost half as much energy as he had in all the time from the birth of Christ to 1850 Since then, consumption has become even more rapid Today some of our garages house two or three automobiles each with hundreds of horses under the hood ready to respond greedily when we push down on the accelerator Jet aircraft gulp fuel, space vehicles are even less delicate The term power-mad applies in a special sense to modern affluent society

Where does all the power come from? Figures show that 98 per cent of it comes from the fossil fuels of coal and oil. Wood and other carbohydrate fuels hydroelectric power wind power, and so on make up only a tiny fraction of the total The bulk of our power is being drawn from those capital energy supplies that nature was perhaps three hundred million years in making and to which she is now adding so slowly that the increase is not worth considering

To simplify energy calculations on a large scale the term ' Q ' has been introduced One Q equals 30 billion tons of soft coal and up to 1850 man had used only about 9 of these Q s In the next century though he used another 4 Q Present consumption has been hiked to about 10 Q per century and it takes but little thought to realize the rate stands to increase for two reasons First population is growing rapidly It is said facetiously that we are doomed to stand elbow to elbow covering the earth in three hundred years, in which case the problem will solve itself and we will need little fuel anyway! Second, and perhaps as pressing as the increase in population, is the per capita rate of energy consumption Powerwise, as the ad men say, we are caught in a two way squeeze

The size of our balance of fossil fuels remaining today is not known exactly and is the subject of a lively numbers game Estimates range from a pessimistic 27 Q to an optimistic 200 Q, which latter includes a large amount of estimated reserves Since by 1975 we will be using one Q every five years, and a further increase in consumption at the rate of 4 per cent per year is perhaps conservative in the extreme, some authorities see an emptying of the supply of gas, oil, and coal in a hundred years or less Even the nuclear fuels that brighten the picture are not inexhaustible Some see fission power gone in an additional one hundred and fifty years and fusion power—assuming that we are fortunate enough to harness it profitably—not good for more than five hundred This is not even the most pessimistic forecast, some authorities see the end in sight much more quickly

As yet we have not looked at the whole picture of our dwindling stockpiles, these materials are important for other reasons than merely as fuels As an example various processes in industry make use of carbon and the chemicals we are prone to burn up as fast as we can to make power Thus, even if we have a hundred years of fuel potential in coal and oil we might do well to save it or some part of it, for other uses than heat or power

Fuel is not our only shortage either Fresh water supplies are scarce in many parts of the world and surely we must have drinking water whether our automobiles run or not Heavy use of fuel to convert salty or otherwise undrinkable water to fresh will make further demands on the supply Solar energy has proved itself in distillation plants, though as yet the costs of capital investment are not competitive with "cheap -power distillation plants Yet a scientist speaking at a recent symposium on the distillation of water saw fit to mention that there was little reason to seek out ways of

converting water using unconventional sources of energy, since we seemed to have enough fuel for another century

We can live a bit longer without food than without water, but we need food too, more than we do fuel Although the United States is now plagued with surpluses, most of the world suffers from too little food If it strains us to feed two and a half billion, what can we offer the eight billion who may be hungry by 2050? Again we seem to be headed toward a Malthusian impasse Nature did not leave us any stockpile of food, we must live on the income she provides Some authorities see a situation so desperate that man will be forced to till every available foot of soil, even farming in summer some areas he must leave in winter because of cold Yet even with this exhaustive use of the land it is pointed out earth can support just so many people, a density perhaps only twice that of present day Japan Interestingly, it is the Japanese who are doing most to use sunlight in growing food, and also for cooking and heating

An acre of ground can be expected to provide crops of about three tons dry weight per year Dr Farrington Daniels of the University of Wisconsin points out the amazing fact that it is *theoretically* possible to produce this same amount—three tons—in a single *day* on the same acre of land! Obviously such a goal is impossible of achievement but it does give promise of the improvement that may be made Already, work with algae called *chlorella* has indicated that perhaps twenty tons a year per acre can be grown, and if the algae can be persuaded to grow in warm or hot water, even higher yields are possible One need for such developments ought not to be missed even today's efficient, mechanized farming requires just about a calorie of energy to produce a calorie of food this is an added drain on our fuel supply

Faced with this emptying fuel bin, what can man do about

it? He could, of course, cut down on his use of power Life might be livable without inefficient two-ton automobiles, jet speed transportation, power lawn mowers, and electric toothbrushes Some people do live with a minimum of mechanical contrivances Surely, if it is impossible to get increased power, man must do without it But all indications are that he will bend every effort not only to maintain the present luxurious use of power but even to increase it This increase will be on two levels, also, when the underdeveloped peoples finally begin to catch up with their "have" brothers One prediction foresees the use of fifty times as much power a century from today

Since voracious man must have power where will it come from? The idea of producing wood for this purpose has been advanced, and investigated thoroughly It seems an attractive proposition, in that man would be living off the income of solar energy, but there is an Achilles' heel to bring the scheme down Hard figures show that if *all* our arable land were used for wood, or even for advanced and efficient algae culture, the fuel produced would provide only 10 per cent of the requirement of the world's people We would also be homeless—since most houses are built of wood—and would starve to death in the bargain

For those who look beyond themselves to the generations who will inherit the future we make for them, the picture is not particularly bright until we turn to solar energy, the primary source of all but atomic power, and the only supply that is inexhaustible Not even the most avid solar buff suggests switching to a rooftop solar plant tomorrow, but we might well *begin* exploitation of direct solar energy as a substitute and eventual replacement for our fossil fuels, and finally as a supplement to nuclear energy—which even optimistic engineers see as delivering only 10 per cent of our needs within the next twenty five years

We have seen that the world uses about 1 Q of energy each year Yet in a year the sun drenches the earth with not one-tenth of a Q or 10 Q, but 2,300 Q most of which is unused! The sun offers a tremendous potential in energy, not just for the few but for every human being on earth The po ver is there for the taking

This taking, unfortunately, is not easy for men spoiled by the luxury of stored energy It is not as easy as digging gashes in the ground and mining coal, or drilling holes into handy subterranean storage tanks of gas and oil But surely the harnessing of sunlight should be a far easier task than that of unleashing the atom on which we have spent many billions of dollars and which remains a tricky and treacherous source of power

Nuclear power is by nature the domain of government and requires the spending of huge sums However though the moon seems in danger, nobody owns the sun and sunlight falls in all our backyards It is apparently true that our standard of living depends on the energy available to us and solar energy falls with no regard for race color or creed It obeys only the laws of physics and of geography and thus we have a wide solar belt between latitudes 40 degrees north and south within which there are large amounts of available power As luck would have it, most of us already live in this belt and many of the poor parts of the world are blessed with even greater solar riches than their presently more wealthy brothers Nature has provided for us royally with a potential far beyond our dreams, in spite of the easy lives we have led on the fuel reserves inherited with the earth

Light Harness for the Sun

A logical question at this point is why we are not making use of this unbelievable bonanza in the form of solar energy

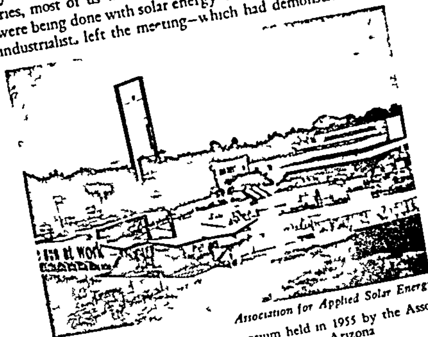
The answer, of course, is that we *are* using it and have been from the beginning All our energy—except atomic and nuclear power—comes originally from the sun A solar-powered radio draws on the sun directly, but a gasoline fueled automobile also uses solar energy—stored solar energy, in which the sunshine of ages ago was trapped in the earth until reclaimed by oil drillers

The hydroelectric dam is an example of solar power though it is interesting to note that the energy of sunshine falling on the surface of Lake Mead is five times the output of the generators at Hoover Dam! The windmill depends on the sun and even the tides are a form of solar—and lunar—energy, since they depend on the pull of those celestial bodies There are a number of tidal power schemes in operation today, but their total output is tiny compared with conventional power plants Harnessing *all* our tidal power would not take care of more than a fraction of 1 per cent of our needs

Our food and lumber come to us courtesy of the sun, so does rainfall, and so do the fish we get from the sea We were born of the sun and depend on it for sustenance But outside this more or less passive acceptance of the sun s bounty we have done little with its energy potential The ancient Egyptians believed that the sun-god, Râ, journeyed during the night through an underground and hellish river so he might rise again next morning in the east There are still people today in some lands who think that the sun steals back across the dark night sky But we, in the sophistication of our laughter, are perhaps more ignorant than they While the savage at least worships the sun, we know little of it, care not much, and do even less about it

Some effort has certainly been expended toward providing solar devices for use in cooking heating, and even pumping for possible use in underdeveloped areas of the world A tiny group of solar energy partisans in several lands have

long pursued their research unsung and little helped As recently as 1955, when the infant Association for Applied Solar Energy held a world wide solar symposium attended by one hundred and thirty scientists from thirty seven countries, most of us were amazed at even the few things that were being done with solar energy Solar scientists and some industrialist, left the meeting—which had demonstrated en



Association for Applied Solar Energy

Solar exhibits at the world symposium held in 1955 by the Association for Applied Solar Energy in Phoenix Arizona

gines, stills furnaces and a variety of cookers and heaters—highly encouraged A rash of material flooded the press and the popular magazines touting the wonders and great potential in solar energy

Unfortunately most of this information was of a gee whiz! nature and did more harm than good Fanciful drawings of homes roofed with solar batteries and autos merrily bowling along on free sunshine were taken too literally and

when the public learned that such a roof would cost hundreds of thousands of dollars and that the solar car was as far away at the moment as anti-gravity screens, interest waned

The one truly encouraging development was the Bell Telephone Laboratories' solar battery, an honest-to-goodness breakthrough in solar energy technology Where earlier photocells had efficiencies of only a fraction of 1 per cent, the new "semiconductor' material yielded about 5 per cent at the outset and in a few years jumped to 12 per cent with an occasional 14 per cent cell produced Scientists foresaw a possible increase to 20 per cent efficiency and a reduction in price to make it more practical

On other fronts a few solar-heated homes were built, and there were jokes about people living in glass houses or Macy s window No one worried much that one-quarter of our fuel is used for space heating The Department of the Interior researched solar stills for reclaiming salt water, and there was a flurry of interest in the solar furnace for research and perhaps even as an industrial tool After all, the French did have such a device actually in operation. Our Air Force announced grandiose plans for a furnace with a mirror one hundred feet—or maybe even two hundred feet—in diameter Solar radios were marketed, though not very successfully Toys run by the sun were demonstrated along with experimental electric shavers and beacon-light flashers We were treated to solar chicken coops, foil-lined solar "baths," and solar hay driers

Widespread use of solar energy did not come The Air Force decided not to bother with its furnace Electric plasma techniques yielded high temperatures and didn't require huge mirrors and clear skies The biggest furnace in the United States was a 28 footer built by the Army Quartermaster Corps for research into the effects of nuclear blasts

and other high temperature work Pilot model solar stills were built and mathematicians gloomily showed on paper that costs were just too high to compete with conventional water production Even in areas where other power was not available it was pointed out, to irrigate an acre of ground by means of solar-produced water would take two additional acres for solar heat collectors

Nothing daunted the handful of solar scientists and engineers continued to work A few interested people in government poked and prodded to get government funds for various projects Experiments were made with solar air conditioning

Solar water heaters simple and time tested did begin to increase in number as better materials became available and engineers designed equipment with greater efficiency The boom in swimming pools brought with it some demand for solar heaters to lengthen the swimming year

Solar-powered radios became a reality in remote areas not only in the United States but in the Amazon jungles and in Africa as well The International Cooperation Administration sent solar powered listening centers to small communities in Paraguay and planned the same program for India, Pakistan and Afghanistan

The United States Agency for International Development ordered one thousand transistorized television sets suitable for solar power for installation in remote areas, incidentally getting itself accused of global boondoggling Another application of solar energy was to power a seventeen-foot collapsible boat designed by AID for transportation on the jungle rivers of Surinam in South America In this intriguing application solar batteries roof a sun shelter on the boat and provide two hundred watts of power for a small electric trolling motor to move the boat along at three knots The solar batteries also provide power for radio communication and for operating a small electric drill

The solar boat unfortunately became a controversial issue Branded by some as another solar boondoggle, the project was halted just before the boat was completed Solar researchers have been hamstrung on other fronts and for other reasons too Lightweight reflector stoves offered at low cost in India have not been accepted by the natives, who still would rather roam the area looking for scraps of wood or animal dung to burn for fuel In our southwest Indians and Mexicans exposed to the same kind of solar cookery decided it did not do a good enough job on the *frijoles*, and interest lagged Efficient solar ovens are of little use at night when many primitive peoples are accustomed to cooking their big meal and for this reason have not met wide welcome Frustrated cooker designers learned that any departure from standard operating procedure must take into account not only local economy but local custom and preference as well

While the people for whom the solar cookers were first developed stayed away in droves, some adventurous campers and backyard cooks did buy commercial models in a variety of types Hobbyists built all sorts of electronic gear using solar batteries, and some "hams" boasted of real DX performance on fractional watt solar rigs

The pioneering Association for Applied Solar Energy weathered the solar storm Housed at Arizona State University, and with funds from the National Science Foundation, AFASE continued to act as a clearinghouse for information and to stir up interest for further conferences on solar energy

In 1961 three were held, including the UN Conference on New Sources of Energy which also discussed wind and geothermal generation of power At this meeting Pope John XXIII addressed the gathering as follows

> In our time in what one might call the technical age of humanity, the possibilities for the utilization of energy have

cious fuel to dissipate solar energy which would be better put to use to power the cooling mechanism

Another broad area of solar research was simply that of pinning down more exact values for the solar constant, and other quantitative analysis The study of solar flares, those vast outpourings of radiation that not only confuse communications on earth but endanger man in space as well, proceeded carefully at the Air Force laboratories at Sacramento Peak in New Mexico and at other places

All this diligent research was fine, of course, but it was seldom reflected in practical applications Progress was so slow as to be almost imperceptible outside the research laboratory The journals published scientific articles but interest seemed to be at an academic level with little or no hope of ever being reduced to practical application If the use of solar energy is inevitable, and even imminent on a relative scale, why the dragging of feet? The reasons, we find, are many and compelling

Barriers to Solar Energy

Sunshine is plentiful but its energy is diffuse and at a low temperature This energy is also variable and requires a storage system to make it available whenever needed There is something else too, a strong hint of black magic or chicanery, in the notion that we can pull energy out of thin air

Among the factors that make up the conspiracy against the sun perhaps the strongest is that of inertia The dictum, "If it was good enough for grandpa it s good enough for me and the kids' sums up this phenomenon So you could heat water with the sun or cook a meal on a reflector stove So what? You could also probably cook with music if you worked long and hard enough at it but what would be the point? You could still buy a million Btu s for a quarter, in

kerosene, and it was so easy to strike a match or turn a valve or push a button

Cheap conventional fuels, then, are another reason for not pushing solar energy applications A camper can buy a gasoline stove for half what a folding solar reflector would cost and it does little good to point out that he could also use the latter for an umbrella when it rains! The prospective buyer of a solar house-heating system is faced with a capital outlay much greater than that required for a gas or electric system against the promise that his solar heater will be economical over a long period Solar energy is free, to be sure But the taking isn't

The fact that 75 per cent of the sunshine hits water is a consideration, too And even though a square mile of sunshine seemed to be equivalent to three million horsepower, engineers shuddered at the thought of erecting a collector that size It was easier to rock along on coal and oil, sure that Providence would not let our descendants down As luck would have it, Providence didn't

Under pressure of war the power of the atom was harnessed For years men of science and science fiction had been dreaming of extracting enough energy from a thimbleful of material to drive an ocean liner around the world When the smoke and debris cleared away after the war, it seemed that we actually had succeeded in doing just that A pinch of uranium could produce the power of tons and tons of coal so who cared if coal *was* getting scarce! Scientific man had triumphed, though many men of science were frankly amazed to see the atom licked sooner than the sun But money for research and development seems to guarantee the successful carrying out of any scheme

Some brave men still had the conviction that our future yet lay with solar energy In 1959 Senator Alan Bible of Nevada a state which reckons its sunlight an asset second

only to its slot machines, proposed setting up a research fund of $10 million for solar energy Introducing Senate Bill 2318, Bible said in part

Some one once calculated that the enormous power involved in the huge atomic energy reactors at Hanford Washington, does not surpass the solar energy which every day in the form of sunlight falls unused upon the roofs of the Hanford buildings To express it another way there is more energy received from the sun on a half square mile on a sunny day than there is in one pound of U 235

The bill was duly referred to the Committee on Aeronautical and Space Sciences, the group which seemed to come closest to sun power No favorable action was taken More recently, Senator Hubert Humphrey of Minnesota has introduced a similar bill which is having about the same luck

Alongside the glamorous atom solar energy was a drab country cousin To wreck its chances further, along came the hydrogen bomb and the suggestion that man could duplicate the process of the sun in such a device Fusion was hailed as far more wonderful than fission, though some thoughtful scientists suggested it might be better to keep the fusion power plant and its multimillion degree temperatures at a safe distance, say 93 million miles The fuel for this exotic power plant is deuterium or heavy water, and everyone knows that the earth is mostly water anyhow Our problems were solved and surely fusion would provide for us as far into the future as anyone could see

The fictional Russian philosopher, Kuzma Prutkov, decided that the moon is more useful than the sun, since it shines at night when light is needed while the sun is of little use in daytime since it is light anyway! In such a fashion we too dismiss the importance and potential of the sun Astronomer Donald Menzel has perhaps put his finger on

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The fictional Russian philosopher Kuzma Prutkov decided that the moon is more useful than the sun, since it shines at night when light is needed while the sun is of little use in daytime since it is light anyway[1] In such a fashion we too dismiss the importance and potential of the sun Astronomer Donald Menzel has perhaps put his finger on

the reason for our apathy He likens the sun to a husband who is so dutiful and dependable that he is not appreciated In fact, the sun's very regularity keeps us from even noticing it The squeaky wheel gets the grease, and the sun is generally just too quiet

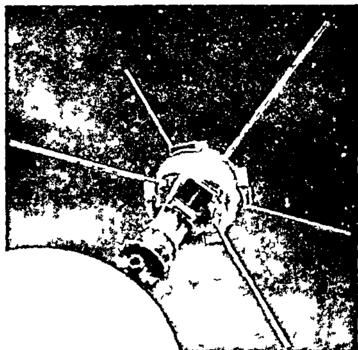
Solar energy then, or at least its fruitful application seemed doomed to wait until the day of reckoning was nearer at hand, when man would actually scrape the bottom of the stockpile the sun had willed him Had it not been for this stockpile he would have learned long ago to use direct solar energy Later, had it not been for the apparent promise of the nuclear fuels, he might belatedly have begun to learn But man, a natural being, behaves in a natural way Like water obeying the law of gravity, he seeks the easiest course In 1957 something happened to change that course

Space Flight and the Solar Boom

Literally from a clear sky came the boost that solar energy sorely needed The exploration of space lifted itself from the pages of science-fiction magazines and became reality Russia lofted Sputnik I to open a new and challenging era The United States followed suit and space was soon sprinkled with dozens of satellites and probes It was shortly evident that once in orbit or on their way in space such vehicles had need of a power supply, and the solar battery, still too expensive for most earthbound applications rose to the occasion like a champion

In this modest debut, a few solar batteries of an early type were rigged to the Navy s Vanguard I a fittingly unsophisticated space vehicle Within a few weeks of launch the conventional storage batteries mounted in Vanguard went dead Not so the solar batteries On every pass they faithfully beeped out their reassuring message Five years later,

The power output rose from a few watts to several hundred and then space planners boldly asked not for watts but *kilowatts*, a kilowatt being more than one horsepower Science fiction was full of vivid descriptions of hyper-space drives, anti grav screens, and force fields, but no detailed



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The Vanguard satellite showing mounting of solar batteries.

blueprints for accomplishing these exotic propulsive methods. Nuclear power was a more logical candidate but with it come problems of shielding waste disposal, and so on Contracts were let for nuclear reactors for space power plants they were also let for solar powered plants

Out in the clear hard vacuum of space solar energy at last came into its own for two reasons There is more sun shine there than on earth And that s about *all* there is A space ship traveling to Venus could not stop at filling stations along the way, but perhaps solar energy would make such stops unnecessary All of space became one vast fuel tank Today there are 15 kilowatt space solar power plants being developed There are dreams of larger ones with huge collectors of thin plastic generating a kilowatt of power per kilogram of weight with the same plastic also forming a huge solar sail to kite the spaceship along And the Russians have even described a plan for plating the moon with a coating to make it a huge power plant in the sky!

The Path Ahead

While many authorities feel that nuclear power will be the ultimate in space, a top official of NASA recently stated that *all* space vehicles to be launched for the next several years will use solar power of one kind or another Starting with solar batteries the applications will progress to thermoelectricity thermionic conversion thermal mechanical engines using liquid metals as a working medium and perhaps more sophisticated systems such as solar heated hydrogen jet engines and ion propulsion

There is a boom in solar energy at the moment then, a boom fostered by man s leap into space The lowly sunbeam that couldn t make the grade as a cooker for Asians or house heater for Americans is now a glamorous space age baby and growing rapidly on the diet of dollars from various governmental agencies eager for space power

Wartime development of radar eventually helped bring TV into most homes The use of solar energy as a space

power source has already hinted the possibility of global communication and education through such a medium, and may lead to many more practical applications on earth Man found helium in the sun, now he seems to be discovering solar energy by looking into space

2

The Solar Boom

World War II spawned the rocket, and inevitably the dreams of space flight began to become reality in the fumbling years after the war German experts were uprooted from their defeated homeland and went either east to Russia or west to the United States Shortly thereafter modified V-2 missiles left over from the war began to poke inquisitively into the blue sky at White Sands Proving Grounds and elsewhere Slowly, more sophisticated designs followed them until missile men trembled on the brink of having the power and the technology to loft a missile, or at least part of one, into orbit

'Long play' rockets, their makers dubbed them smil ingly though how prophetic that term was few would have been optimistic enough to believe Russia led the way, hurl ing Sputniks I and II around an astonished earth late in 1957 The United States *matched the feat with Explorer I early in* 1958 These first successes were short-lived orbits but in the wings was a surprise Long before a satellite was func tioning in space scientists knew that tracking one would be

a problem The answer other than frustrating visual "Moonwatch' teams was radio communication from satellite to earth Of course such a radio could be powered by conventional batteries but there was another type newly available —the Bell Telephone Laboratories solar battery, invented in 1954 and already a precocious child Its use in space had been suggested in January 1956, and by June 1957 army scientists had already attached some of the treated silicon wafers to a navy Aerobee Hi rocket Such hitchhiking" of experimental equipment was the vogue and it was something of a battle to wangle space aboard the missile for the solar battery test The experiment worked well and a solar radio carried aloft transmitted signals until the missile burned up in re entering the atmosphere The flight had proved the feasibility of sun power for satellite equipment

Working feverishly with the navy scientists, United States Army Signal Engineering Laboratories installed a tiny radio powered by six small solar panels on the Vanguard TV-4 (for Test Vehicle 4) This project was already plagued by several failures of the booster, and there were disgruntled complaints about all the services trying to launch satellites instead of consolidating their efforts and saving time and effort But on March 17, 1958 Vanguard rewarded its backers and confounded critics by placing a satellite the size of a grapefruit and weighing only 3¼ pounds into elliptical orbit ranging from about 400 miles to more than 2,400 miles above the earth Gleeful workers at USASEL received a congratulatory teletype message from the Navy almost immediately

EASTON TO ZAHL ZIEGLER HUNRATH HERCHAKOWSKI, OF SIGNAL ENGINEERING LABORATORIES CONGRATULATIONS! SOLAR POWERED TRANSMITTER WORKING PERFECTLY YOUR COOPERATION ON THE PROJECT DEEPLY *APPRECIATED*

How perfectly, and for how long the solar-powered transmitter would continue to work could not have been predicted by the most widely elated of the crew Nor was the full implication of the feat yet apparent Solar batteries by the hundreds of thousands would soon follow the 108 tiny silicon chips mounted on Vanguard I s six-inch satellite



U.S Army Signal Corps

Closeup of Vanguard solar battery cluster These have operated continuously since March 18 1958

The space age of solar power, the shot in the arm that may well hasten the widespread use of the sun's energy in terrestrial applicatio is, was thus modestly ushered in by a minuscule satellite so small as to be embarrassing to many prideful Americans Yet the tiny ball has been a veritable gold mine in the sky for scientists proving among other things that the pressure of sunlight is appreciable, as the

satellite has actually been displaced about a mile each year in this manner A more mundane result has been Vanguard s use by the Army Map Service to plot accurate coordinates of islands in the Pacific

Of special satisfaction is the fact that despite fearsome radiation from the Van Allen belts constant sandpapering by micrometeorites and the hot breath of dreaded solar flares the tiny satellite continues to beep its radio messages merrily Estimates put the expected life of the satellite at from two hundred to one thousand years and it may well be that the solar-powered radio will continue to "play for a good part of that time In fact, because of Vanguard s per sistence some follow on solar-powered satellites have been equipped with time switches to silence them after a certain period so they will not forever clutter up the airwaves!

Putting the Sun to Work

Vanguard was well named While its tiny solar power plant had a designed output of only a feeble tenth of a watt dozens of later satellites have carried ever larger and more sophisticated arrays of solar batteries In the United States other space vehicles followed each of them bigger and mounting more elaborate gear and instrumentation As an example of the popularity of solar batteries for space use NASA estimates that 154 000 were used in 1962, 410 000 in 1963 and 1964 and 1965 will use 796 000 and 978 000 re spectively This does not count those used by other coun tries of course Russia s Sputnik III incorporated solar batteries as have most of her satellites sent aloft since

Because of the simplicity of even the newer solar battery both in appearance and in operation it is natural to consider it a one purpose device good only for the generation of electricity This happily is far from the case and the solar

battery is already performing other delicate and complex tasks in its space missions For example, it was noted long ago on the relatively simple Vanguard I installation that the solar batteries offered benefits other than just the power they generated Cessation of the radio signal indicated precisely when the satellite passed from light into shade, an important piece of information to tracking stations The reverse effect was true also A satellite launched soon after Vanguard I carried solar batteries whose function was to turn equipment on and off as the satellite passed from light to darkness and vice versa

Even before satellites had proved themselves feasible scientists and engineers were lying awake nights thinking up other tasks for them besides idly sweeping the sky in their orbits Thus each satellite has had little leisure time but has been pressed into service for a multitude of jobs The "eye-in the sky" has long been a provocative idea and such an Orwellian concept for space was a natural development While early satellites were scrupulously shot into orbits that would not lend themselves to such cloak and dagger motives, it was inevitable that projects like the one dubbed Big Brother' be developed Midas and Samos and Vela Hotel are some of the colorful and confusing names that have been chosen but all such orbital sentries have one point in common In order to function they need a constant source of power to monitor atomic explosions, missile launchings nuclear warheads and so forth And solar batteries offer that source plus freedom from any radiation of their own that might confuse the delicate monitoring equipment

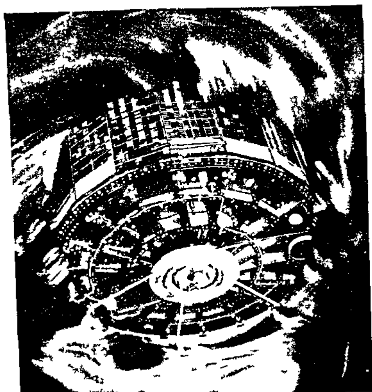
Another kind of eye and one of a more creative nature, is that of the weather satellite Early in the game the proposal was made for a satellite mounting a photocell to scan the earth This simple device would transmit either a dot of light or nothing, depending on the presence or absence of cloud

cover By putting together enough of these white and dark spots it was hoped that weathermen might get a rough idea of what earth s cloud cover looked like from several hundred miles up The scheme was thought overly optimistic by many, but even before it could be put into practice space technology leapfrogged it and came up with a weather surveillance satellite which made the light and dark spot method look as crude as the earliest moving pictures compared with today s three dimensional wide screen Technicolor epics This was Tiros the weather eye made practical by our little friend, the solar battery

The National Aeronautics and Space Agency managed the Tiros program, with technical direction by United States Army Signal Research and Development Laboratory RCA s Astro Electronics Division developed and produced the prototype Tiros I which was launched on April Fool s Day in 1960 and promptly fooled just about everybody by relaying back beautiful television pictures of cloud cover over most of the earth between the latitudes of 50 degrees north and 50 degrees south

With power furnished by 9 200 solar cells that literally formed its complete outer covering Tiros ground away with TV cameras and also monitored infrared radiation and other phenomena With two cameras mounting wide- and narrow angle lenses, Tiros I produced nearly 23 000 pictures And what pictures they were! No longer did man need to gather weather data from widely separated points and laboriously construct a crude and often erroneous, weather picture He could see the world weather at a glance Cloud patterns showed a high degree of organization heretofore only suspected and hardly hoped for Cyclones were observed to have a distinct spiral or vortex cloud pattern even in extra tropical areas—a revelation to weathermen A storm off Madagascar was tracked by Tiros for five con

secutive days jet stream activity was studied, and there was even a weird *square* cloud spotted in an area that proved to harbor tornadoes in Kansas



National Aeronautics & Space Administration

Tiros II weather satellite reflects light patterns during spin test. Solar batteries cover its outer surface

Designed hopefully for three months operation Tiros I came within two days of making good its planned lifetime Mechanical and electrical difficulties shut it down there was no problem with the solar battery power plant

Tiros II incorporating improvements was launched in

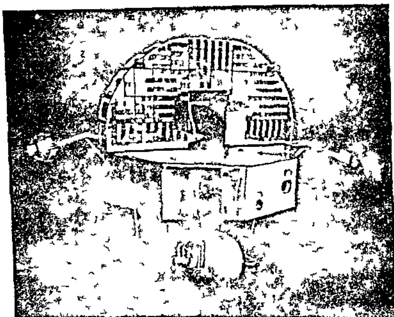
November of 1960 and operated for twelve and a half months Despite an unfortunate smearing of a camera lens by the exhaust of the launching rocket, and various mechanical difficulties more than 36,000 usable pictures were transmitted Supplied by Tiros II were pictures of the ice flow situation in the Gulf of St Lawrence, advance information of a cold front which alleviated a heat wave in New Zealand and observations useful in the launching of the first Mercury capsule in May of 1961 Tiros III brought the total of photographs televised to more than 92,000 Numbers IV, V, and VI continued the good work and provided excellent current information on the weather, useful in launching orbital manned capsules

Such pictures of the weather as it actually happens permit meteorologists to issue analyses within as little as two hours of receipt of the pictures and assure the early bringing about of accurate global weather forecasting The American Meteorological Society in 1961 issued a statement calling the weather satellite an unprecedented means of surveying certain kinds of weather conditions over the entire globe, and by 1962 weathermen were using Tiros data to advance new theories The AMS feels sure satellites will lead to better weather forecasting

While the concept of the weather satellite must be viewed as a whole the vitally significant part played by solar power should not be minimized Each of the satellites carried out its three month life or more, and one functioned usefully longer than a year even then the stoppage was not caused by failure of the solar batteries As was suggested by the pioneering Vanguard I, reliability and long life are basic attributes of solar batteries When a permanent weather satellite is orbited its solar batteries may well power it indefinitely

For many years astronomers physicists and other scien-

ists have dreamed of observatories free of the dust and haze of earth and unhampered by the disturbance of its atmosphere Until the advent of the orbiting satellite the best man could do was to build his research facilities high atop mountains. This helped but it was far from an ideal situation



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OSO the Orbiting Solar Observatory which will study the sun through the clear vacuum of space Notice the banks of solar batteries which power the instruments abroad

What was needed was an observatory out in the vacuum of clear, uncontaminated space There its instruments would record without the degradation caused by atmosphere, artificial lights and terrestrial magnetism This dream is now a reality, and solar-powered observatories study earth and the celestial bodies of interest

4 000 to 7,000 miles and will make possible two-way high quality communication between all parts of the world Two sizes of satellites are being considered two feet and four feet in diameter These would mount even more solar batteries than Telstar s 3 600—4 000 on the small satellites and 12,000 on the larger Higher orbit affords more protection against radiation incidentally, but even the lower orbit of Telstar has a big advantage over terrestrial communication in which signals are bounced off the ionosphere since Telstar is not susceptible to the sunspots which play havoc with radio during those periods of solar activity

AT&T is not the only group active with communication satellites of course Among the others is RCA with its Relay, a similar, 172 pound repeater Hughes Aircraft too is working in the field and its concept is a departure from that of Telstar Most satellites move around the earth in heir orbits Hughes 80 pound Syncom satellite is a '24-hour," or synchronous satellite

The laws of celestial mechanics decree that the farther from a planet its satellite is the slower it may move relative to the planet Syncom will go into equatorial orbit more than 22 000 miles high and will appear stationary in the sky There are important advantages to such a system Because they are fixed and high three Syncoms can cover the earth for communications And radiation harmful to solar batteries is even less at this altitude than that proposed for later AT&T satellites

There are disadvantages too such as the annoying delay in message transmission because of the long distance A synchronous satellite introduces a half second lag into conversation, and requires the suppression of echo so the speaker will not hear this irritating repetition Proponents of the thirty to fifty satellite system also say that it is wrong to put all our faith in only three satellites since failure of one would

knock out one-third of the global network, while loss of one out of thirty would pose no great problem Proof of the better system must wait for comparative tests of both, but whatever the ultimate decision, solar batteries will power our communication satellites Worldwide simultaneous messages imply a worldwide language and perhaps Telstar and its successors can succeed where backers of Esperanto, Io, and other universal languages have historically failed

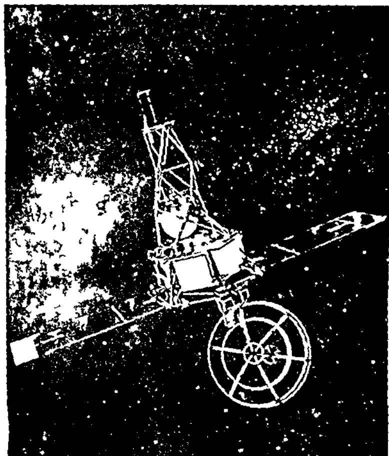
The use of solar power was not long limited to orbital flight Soon space vehicles were departing the earth on trips to the moon and the planets Pioneer V was launched to probe deep into space and its solar-powered radio sent back data from more than 22 million miles out Even this was but a prelude, and our Mariner Venus probe used the sun to send back information from a distance of 36 million miles

Light Talk

Having talked of solar powered electronic communica tion let us turn now to the homely mirror and its use of the sun as a method of sending messages over great distances

As mentioned earlier, Hermann Oberth, pioneer space-flight thinker, envisioned the use of signal mirrors for send ing messages many thousands of miles We have developed some tricky ways of using them to beam a message For example, Telstar mounts a number of mirrors that send messages to watchers on earth

We have always been dependent on the sun for our most important means of communication, without light we could not see or be seen But early in his development man began to experiment with light by bouncing it over great distances, at first accidentally and then on purpose The glint of sun from a watery surface or a smooth rock was noticed with some interest When he had metal man learned to polish it



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Artist's concept of Mariner spacecraft on its long journey to Venus

not only to see himself but also to reflect a spot of light for long distances.

Sunlight surprisingly has a military heritage too. The polished armor of soldiers had an added value beyond protection, first as a distractor of the enemy, and then as a signaling method. A canny warrior could blind an opponent

with a flash from his burnished helmet or shield or call for help at a distance with the same flash Archimedes is said to have developed *an array* of mirrors into a defensive weapon that set fire to the sails of enemy ships at ' the distance of a bowshot a feat duplicated by Proclus during the siege of Constantinople The hostile sailors got the solar message much to their dismay when their ships burned

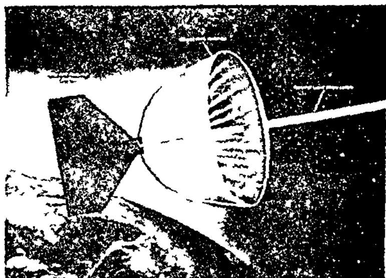
The use of glass mirrors more highly reflective than the early ones of metal, came along in the Middle Ages and the heliograph *was slowly perfected* Named for Helios, the Greek sun spirit, the signal mirror was refined to its modern form in the 1870 s by an Englishman named Mance A telegrapher, he developed the heliograph as an aid for the British Army in India Also used by Roberts in Afghanistan, the heliograph was of great use in several battles Later, in the Boer War, Sir Robert Baden Powell found it helpful when he was besieged *in* Mafeking His Boy Scouts have perpetuated the use of the heliograph, and offer a merit badge for its use

In 1890 the United States Army used the heliograph extensively in another land of Indians, the Arizona Territory General Greely was in charge of this project, which ultimately saw the establishment of some 2,500 miles of *heliograph lines and the sending of many ' heliograms "* One message was sent by the General from remote Bowie Peak across a chain of stations to Prescott then by telegraph to Washington D C

Using six-inch mirrors Signal Corps teams heliographed messages in American Morse telegraph code for great distances in the clear Arizona air One remarkable ' flash' was made direct from Mount Reno to Mount Graham a distance of 125 miles Our expression news flash, may well be an outgrowth of this early term A more typical message was sent from Mount Graham to Colorado Peak by way of

Lookout Peak, with its 97 words transmitted in 22 minutes In one unusual experiment messages were even sent by moonlight, an early form of night letter!

The Boy Scout version of the heliograph, equipped with a key-operated shutter, is fast and capable of sending messages over creditable distances In simpler form the hand-



American Optical Company

Sun powered laser which is expected to permit use of direct sun light to power a system for communicating with satellites and other objects in space

held signal mirror saved the lives of downed fliers in World War II and again in Korea It is standard equipment in many survival kits, and stranded autoists and campers often attract attention with a rear-view mirror or perhaps a shaving mirror, hastily pressed into service It is this very simplicity of the heliograph that makes it such a strong contender for the vital job of space communication where light weight and reliability are of prime importance

The use of light rays for voice communication is an exciting idea that has been made practical by modern technology There is a communication system on the market today called Sun Fone," in which a solar battery is used in the receiver to change light into an audible signal The signal is sent by the transmitter, a simple mirror which is vibrated by sound waves spoken into the mouthpiece These vibrations modulate the reflected light, which must be aimed accurately at the receiver, and thus convert the audible message into a light beam. Built as a toy and designed for short-range communication, Sun-Fone nonetheless has important implications as an efficient communication method

As its space programs began to unfold, the Air Force was aware of the problem of communication in space As part of its research program, Wright Air Development Division gave a contract to Electro-Optical Systems, Inc, to investigate the possibility of using solar communication, in effect a space-age heliograph The result was SOCOM (for solar communication), a system which demonstrated the feasibility of using a light beam to transmit messages through space for distances up to 10 million miles Ground tests were made in the Mojave Desert, using special light-attenuating filters to simulate the millions of miles of space

SOCOM is a learned big big brother of the Sun-Fone toy A double mirror system called a Cassegrainian array, gathers the sun's rays and passes them through a modulating device and then through a hole in one of the mirrors and back to the receiver Electro-Optical has experimented with a number of modulators for encoding a message on the light beam, and the operational version of SOCOM uses a 'stressed plate shutter to polarize the light beam The system to be used for the actual test in space weighs in the neighborhood of thirty-five pounds, incorporating special lightweight plastic mirrors that weigh less than half a pound per square foot of area

The solar communication system is not yet perfected of course The first message sent to test SOCOM in the desert was What hath God wrought' the historic message sent on Morse s telegraph SOCOM required five seconds to transmit this message a bit longer than it takes to say the words However further improvements should make normal voice communication possible and even faster transmission of information by other techniques already in use in radio and telephone

As often happens other scientific developments seem to come along at the right time The laser is one of these an invention by engineers at Hughes Aircraft for amplifying a light beam in much the manner that radio waves have long been amplified Although light is an electromagnetic radiation as are radio waves it had not been possible to amplify this part of the radiation spectrum prior to the invention of laser which is an outgrowth of the earlier invention of maser Back in the mid 1950s Ruby Maser was a name many of the unenlightened must have taken for Miss Electronics of that year Maser is an acronym for Microwave Amplification through Stimulated Emission of Radiation In one application a ruby rod was pumped with energy and emitted energy at a higher level In 1960 Hughes researchers found a way to perform an analogous operation on visible light and the word light" took the place of microwave to make the name 'laser'

When a ruby rod or other suitable material is pumped or pulsed with a proper light source light waves are emitted from the ends of the rod These stimulated radiations have two remarkable properties in that the light is both amplified and made coherent In other words the light is transmitted "in phase rather than with the hodgepodge of frequencies found in natural light The important consequence of the laser is the emission of a very bright, very

narrow beam of light whose rays are nearly parallel and do not spread out over a distance as does ordinary light

As an example of the power of this amplified and coherent light laser beams have been used to burn holes in diamonds and steel, to weld materials varying from metals to the cornea of the human eye and to bounce a signal from the moon This last feat is something never accomplished with unlasered light The characteristics of the new light beam make it ideal for communication, particularly in space

Recently the Air Research & Development Command awarded a contract to American Optical Company to develop a special kind of laser—one pumped continuously by the sun The conventional laser of course is powered by a more or less conventional source However for use in space where weight is a vital consideration a pumping source weighing nothing would be highly desirable The American Optical laser, then uses the sun's rays to power a ruby rod laser A large reflecting mirror focuses sufficient blue and green light from the solar spectrum onto the ruby rod to cause it to go into continuous oscillation The resulting beam of light is some ten times as intense as the direct sun and its extreme narrowness permits communication over great distances in space RCA has also produced a sun-pumped laser

A modulation system is incorporated in the sun powered laser, as in the SOCOM unit The advantages of the laser communication in addition to light weight and long range, are simplicity and long life together with self contained operation Of great importance too is the fact that the laser operates at much higher frequencies and over a greater bandwidth than radio These factors provide higher transmission speeds and more available channels for separate messages

To reach farther out into space networks of lasers are

proposed, relaying messages from one collecting mirror on to the next much as earthbound microwave systems do to day Also proposed are more aggressive uses of the solar laser, including an anti-ICBM weapon whose intense rays could destroy hostile missiles in space

Oberth s fantastic scheme of ' death ray' mirrors hung in space is ridiculed by Russian writers who have other ideas on how best to use mirrors It has been suggested that they could be used to light up cities at night one expert estimating that a thirty-meter mirror could provide as much light for a town some twenty kilometers across as would a full moon Not to consider the romantic aspects of such an artificial moon! Disregarding the wilder suggestions, it is still obvious that there is much magic in mirrors and that they can do many things with sunlight

Whether we continue to use radio frequencies for communication or change over to those of visible light or infrared remains to be seen In all probability both types will be used, depending on the job at hand and its requirements with regard to distance, message handling capacity security, and so on Whichever way communication goes, however, the sun is sure to play a big part in the process and solar power will be used increasingly to speed the word along

The Busy Sun

These are some of the jobs that solar energy can and will do in space Besides reconnaissance orientation weather monitoring communication and astronomical research, there are more mundane chores like the heating and cooling of space vehicles cooking of food growth of algae for food purification of air and water, guidance control and navigation We have discussed the reasons for the remarkable success of solar energy applications in space and some of the

intriguing possibilities for the future As was pointed out, many of these developments carry corollary benefits for us groundlings, who may one day be tapping sunlight the way we now do natural gas

Particularly gratifying is the use by private enterprise of solar energy in a practical space application Until AT&T's pioneering commercial Telstar, it was primarily government money that pressed solar energy research forward All branches of the military, and civilian agencies like NASA, provided the dollars to get solar energy off the ground Hopefully this was but a priming of the pump, and power from the sun will continue to flow in an ever greater and ever more economical stream, not just for space applications, but on earth as well

In the following chapters we will discuss in more detail the needs for power in the space age and how solar energy fills the bill It is a fascinating story and one with a broader scope than most of us realize

many pounds of expensive rocket fuel for each pound of payload placed in orbit or launched as a deep-space probe In other words to put 10 pounds of batteries in orbit might require more than 100 pounds of fuel, fuel which has weight itself and uses up much additional power with no useful return If we weigh a conventional 15-kilowatt generator with sufficient fuel to run it for a year, and calculate the size of a rocket big enough to lob it into space the results are discouraging This is the reason for all the current research into special power plants to accompany our new and sophisticated space vehicles aloft

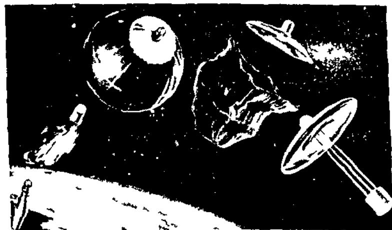
Three Ways to Go

Three basic methods of producing electricity are under study for space applications chemical storage, nuclear power and solar power All these methods and some other unusual types have been used or are being considered for use in space power applications

First and simplest is the chemical storage battery in its many and varied forms A small satellite radio could be powered with a flashlight battery but nickel cadmium and silver-zinc storage batteries are more efficient and it is these that are used A more advanced battery is the much discussed fuel cell, which recombines fuels such as oxygen and hydrogen to produce electricity directly Existing batteries have conversion efficiencies of 70 per cent, fuel cells potentially can better this figure But good as they are both kinds of batteries require fuel which weighs concrete amounts and which is exhaustible For a mission of only a few hours a chemical battery is obviously the answer for power in space But if we want a supply for a week or a year the picture changes

Another power source as we might expect in the atomic

age, is nuclear energy With atomic piles now delivering power for industry and utilities, it is natural to consider this method for space Farthest along at the moment are generators fueled with radioactive isotopes such as uranium 235 SNAP (Space Nuclear Auxiliary Power) plants in several configurations with varying outputs are being developed However, while the radioisotope approach looked good at



Goodyear Aircraft Corp

Artist s concept of inflatable solar reflector for space power plant Plastic balloon is inflated with gas hot wire burns away unwanted part power plant slides out on telescoping mounts Mirror is 45 feet in diameter

the outset, and the operation of small pilot plants has been accomplished, serious doubt now exists that there is sufficient material available to fuel an appreciable number of radioisotope power plants Since the half life of some isotopes used is quite short, the power plant might also have a relatively limited life

More likely to work are scaled down nuclear reactors using more readily available atomic fuel Reactors for space

are being developed to produce many kilowatts For example, one Wright Air Development Division project called SPUR (Space Power Unit, Reactor), is to have an output of 300 kilowatts, and perhaps 1,000 kilowatts with further development Thus the term megawatt or million watt, is often applied to the power levels possible with nuclear power SPUR is designed to deliver about one kilowatt per eight pounds of weight an amazing performance compared with conventional power plants, however, this weight does not include the necessary protective shielding Shielding is one of the disadvantages of the nuclear reactor, as are waste disposal, fallout danger, and so on

A furore of sorts has already been provoked by the SNAP III plant used in the Transit satellite The atomic package was demonstrated to President Kennedy in the White House, and many scientists including Dr Ralph Lapp, protested that an accident could have killed those within a sizable radius

We come now to our third basic power source for use in space that of solar energy Here we have the interesting paradox that, while this is considered the most visionary of all three, it is today the only power plant being regularly sent aloft and this condition is likely to prevail for some time

Although space flight itself seems to have boomed solar energy, there are inherent reasons for the spectacular success of solar power in space One is obvious—we use solar energy in space for the same reason men climb Everest, it is there In fact the higher we climb the more solar radiation we can make use of On earth there are roughly 1 000 watts of available energy per square meter of exposed surface In space this figure increases by 40 per cent Thus the solar panel that develops 100 watts at sea level might well deliver 140 watts in orbit

Another reason is that the solar battery functions more

a solar battery is very light to begin with But this lightness is extended to the nth degree by another characteristic of the cell—its long life For a short mission of a few orbits it might well be more economical to use a storage battery than a solar battery, since the chemical battery is far cheaper and for short periods its weight can match or beat solar batteries But extend the mission to a week or two and immediately the solar battery comes into its own

Chemical batteries are generally rated in watt hours per pound Let us say a particular battery delivers 10 watt hours per pound of weight We find that a solar battery delivering 10 *watts* of solar power may weigh 5 pounds and thus is un attractive, particularly at a cost of perhaps $200 per watt But suppose we operate both systems for 5 hours and re check our figures Already the solar battery is competitive on a weight basis having delivered 50 watt hours for a weight of 5 pounds We notice something else, too The chemical battery is now dead unless we recharge it The solar battery is good for another five hours at which time its watt-hour weight is halved At the end of 1 000 hours it will have delivered 10 000 watt hours or 2,000 watt hours per pound Even at the high initial cost it will now be a far cheaper investment than the chemical battery

Long life implies reliability, which battles light weight for the most importance in space missions Although the con cept of the solar battery and its fabrication are by no means simple its operation is The solar battery is outwardly a passive or static device, with wires attached and sunlight supplied it produces electricity directly and continuously The only moving parts are electrons and apparently there is nothing to wear out Even the early batteries in Vanguard I have proved that they can function for five years Theoreti cally, improved types can operate even in the radiation of space for an indefinite period twenty five years has been suggested as a realistic figure

It costs a fortune to lift a satellite into space, solar power provides a way of getting the most for our large investment in space hardware Since solar power does away with fuel weight completely, it is ideal for space missions where weight is a critical factor The longer the mission, the more efficient the solar engine, and for probing deep into space it really shines

To get a better perspective of how the three basic power systems compare, let us consider an actual mission A typical project is a NASA unmanned probe to journey through space to the planet Mars This mission requires 150 days, during which time a power level of 100 watts is needed Here on earth we burn 100-watt bulbs in our lamps with little regard for the amount of power they consume, but the difficulty and expense of burning one continuously for the Mars trip may jolt us somewhat

As we have seen power can be supplied through energy storage or through a power conversion system Energy storage includes the use of batteries or the not yet available fuel cells Using the best storage batteries it is thought possible to make, power for the modest Mars probe would weigh almost two tons! Discouraging as it seems, even batteries yielding 100 watt hours per pound add up to 3 600 pounds and the Mars project takes on the aspect of an elephant carrying a transistor radio for a payload

When the fuel cell is available, with its hoped for 250 watt hours per pound we can cut the weight of our energy storage system to a little over 1 400 pounds However the prospect is still not appealing since the probe s total weight can be only 300 pounds

Instead of energy storage which looks hopeless at this point, let s consider power conversion How about atomic power? If a thimbleful of fuel can drive a steamship around the world surely it won t require thousands of pounds to go to Mars Happily it doesn t and for a weight expenditure

of only 35 pounds we can provide our needed 100 watts for the 150 day mission This seems to be the way to get the job done except for two drawbacks in the use of our atomic plant First, it emits dangerous radiation and must be carefully handled by technicians and launch crews In case of an



Electro Optical Systems Inc

Lightweight mirrors reflect additional light onto solar batteries to more than double their output Mirrors would be folded during launch of space vehicle

aborted launch there is danger of contamination and if the probe is planned to land on Mars the same will be true Second radioisotope electricity costs come pretty high Estimates place the cost *per watt* as high as $5 000 and to burn our 100-watt bulb on the Mars trip may cost us $500 000

Now let us check into another way of doing the job A

solar battery panel is also a power conversion system and one to provide us with the necessary 100 watts would weigh about 20 pounds a bit more than half what the atomic plant weighs There is no radiation hazard with the solar panels, and they depend for operation not on the half-life of radioisotopes but on the somewhat longer life of the sun Practically speaking, 25 years seems a good estimate of the lifetime of a solar panel This leaves but one factor to be considered, that of cost Solar power conversion, we understand is quite expensive, but it comes as something of a surprise to learn that the cost of our 100-watt plant would be $100 000, or only one-fifth that of the atomic plant! And if the space probe is recoverable, the solar panels could be used again and again, long after the radioactive isotopes flickered out their last heat

Such talk of 100 watt solar panels is commonplace today just a few years after Vanguard and its one tenth of a watt array And far from being just talk, such panels are a fact and performing continually out in space The same men who would have laughed loudest in 1958 when someone suggested such sizable power packages are now designing them into satellites and space probes Outputs of up to 275 watts have been achieved, and panels on the drawing board make these seem like small test modules

The most ambitious proposal yet is tha of Westinghouse Electric Corporation s Aerospace Division—a giant panel array generating *four kilowatts* of electricity! Under contract to the Air Force Westinghouse demonstrated the feasibility of such a solar battery power plant for use in satellites This concept vaults far beyond earlier cautious talk of a possible one kilowatt solar battery panel

To produce 4 kilowatts 130 000 individual 1 by 2 centimeter standard solar batteries are required These are mounted on lightweight metal backing Reflector channels

concentrate sunlight on the batteries, doubling the amount of light they receive and thus increasing the power produced Incorporated in the panel would be orientation equipment to keep it constantly facing the sun for highest efficiency Storage batteries would also be carried to provide power during dark periods of orbit Certainly such a large solar battery array would be expensive but balancing its cost are such factors as high reliability and long life Perhaps most important is the fact that the solar panel is available *now*

Cutting the Price of 'Free' Power

Thus far, and with good reason our attention has been focused on the solar battery However, although it can presently outperform even atomic energy in space it remains a very expensive means of providing power Let us therefore take a look at other ways of using solar energy for space power There are several which promise to be much cheaper to use

Since it is generally agreed that electricity is the best form of power for space use our power plant should ultimately convert its output to that form The solar battery changes sunlight directly into electricity there are other solar methods for producing electricity that are not this direct Thermoelectricity and thermionic conversion for example, both use the heat of the sun rather than its light and require intermediate steps to do this

These are still, in effect, direct conversion of solar energy to electricity in static devices There are also dynamic solar engines like those conventionally fueled heat engines we use on earth to generate power for industry and our homes The turbogenerator is one of these and because of

its very high overall efficiency it is a likely candidate for space power applications

Under development now are dynamic solar-powered systems for developing up to fifteen kilowatts of power, using mercury rather than steam boilers

Another type of thermal-mechanical engine being developed for space use is the Stirling-cycle engine, which was invented by the Reverend Dr Robert Stirling in Scotland back in 1816

As we shall see in the following chapters, all these methods are being developed for actual space power plants, and may provide cheaper electricity than does the simpler solar battery

The Power of Concentration

By now it may be obvious that the solar-powered plant is pretty much the same as the nuclear- or other-fueled thermal mechanical plant, except for the energy source Since direct sunlight is sufficient only for solar battery operation, it is necessary in thermoelectricity and thermionic emission to boost the temperature with some sort of concentrator In this particular, the solar power plant is as unwieldy as its nuclear competitors and the shielding they must carry One 3 kilowatt solar engine for example calls for a 32-foot parabolic reflector mirror Increasing the power to 15 kilowatts fortunately does not boost the mirror size to more than 42 feet, but even this is a huge engineering undertaking when we consider that the reflector itself must not only have a very high degree of accuracy and be capable of pointing directly at the sun but must also be small enough to fit within the confines of a fairly small nose cone on the missile that boosts it into space

Early solar collectors were simply surplus searchlight

mirrors and "searchlight quality is generally considered sufficient for solar collectors for space power use Some searchlight mirrors give concentration ratios as high as 15,000, and 10,000 is fairly common Standard searchlight mirrors are very heavy and fortunately these high concentration ratios are not necessary for solar power plants Using searchlight mirrors as molds lightweight mirrors have been made of fiberglass and honeycomb materials Offering efficiencies of up to about 80 per cent and concentration ratios of 1,500 to 2,000 these reflectors weigh as little as one quarter pound per square foot of area

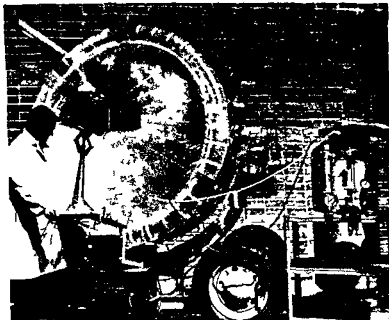
A five-foot mirror built by Electro Optical Systems for a NASA *Mars probe* is one piece made of thin nickel Electro-formed and electroplated this excellent mirror is better than 90 per cent efficient and weighs nineteen pounds Larger one piece mirrors do not seem practical for a number of reasons and designers must resort to folding furling and other devices This of course results in less efficiency

Besides the large unfolding and unfurling segmented mirrors lightweight plastic inflatable reflectors have been proposed for use in space as solar energy collectors and the feasibility of this idea has been amply demonstrated by the successful launching of the huge Echo satellite Even with efficiencies of only 35 per cent the plastic reflector is attractive because of its very low weight

Early proposals dating back several years suggested using large inflated spheres one hemisphere of which was silvered and served to focus sunlight within the sphere A more sophisticated idea consists of inflating a sphere part of which actually adopts a parabolic shape This parabolic sector is made rigid with a backing of foam that sets in place permanently and then the rest of the sphere is automatically cut away with a hot wire leaving the required parabolic reflector The advantages of such a scheme are immediately

obvious Mylar plastic is an excellent reflective surface and is about the lightest practical material known for such an application It is also inexpensive and it can be packed tightly into a small container

Another approach to the solar collector is the Fresnel lens



Electro-Optical Systems Inc

Small inflatable solar reflector being tested Plastic is desirable for space use because of light weight and easy packaging

This clever compromise, long used in the optical laboratory and in certain lighting fixtures in effect cuts a thick parabolic mirror or lens into a great number of concentric rings and then flattens them into a thin plate or sheet sometimes of plastic Hobbyists are familiar with plastic Fresnel lenses more than a foot in diameter and only about one sixteenth of an inch thick capable of being rolled to fit a mailing tube

Flattened out, a Fresnel lens in even this small size can generate temperatures of around 2,000° F Large metal "masters" are turned on a lathe to a precision of parts of thousandths of an inch, and from these are produced thin mirrors or lenses of a size suitable for use in the Stirling cycle space plant Since the Fresnel lens is flat it more easily solves the difficult problem of holding each point of a large mirror to the extremely tight tolerances necessary Folding is also easier, since simple hinges suffice

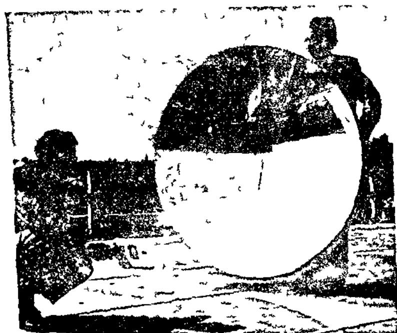
The scheme of concentrating sunlight would seem to be a good one for solar batteries as well, and much effort has been expended in this direction A fraction of a square inch of solar battery may cost ten dollars Mirrors obviously can be made for a much cheaper price so why not concentrate twice the amount of sunlight on the cell and get twice the output? Or five or ten times? It is an appealing idea and Russia claims a solar panel of less than one-half a square meter in area producing 150 watts of power, which is some four times the output of American panels that size This was done, according to Russian scientists by increasing the sun light on the solar batteries tenfold

In experiments carried out in this country, such a high concentration has heated the batteries so much that they cease to function at all However by using a concentration of only some two or three times, researchers have succeeded in doubling the electrical power output of the cells and effecting a slight saving in weight as well

A solar collector pointed away from the sun is as useless as a bucket without a bottom and the matter of orientation is a disadvantage of solar- as compared with chemical or nuclear powered batteries since it makes no difference in which direction the latter point

Where orientation of panels to face the sun was out of the question early installations of solar batteries took care

of the problem simply by over-designing That is, sufficient cells were placed about the surface of the satellite so that, regardless of its position, enough of them would always face the sun For maximum efficiency the surface of the solar battery must be at right angles to the sun's rays it intercepts



The Boeing Company

Engineers check accuracy of solar reflector made for use in space This lightweight mirror weighs only a few pounds

However, efficiency decreases only by the cosine law, which means that a misalignment of as much as thirty degrees degrades performance only about 15 per cent

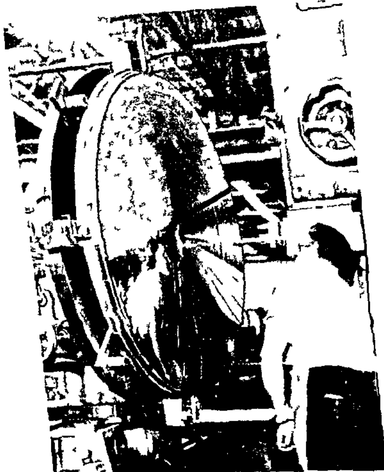
Some spinning satellites such as Tiros have their surfaces covered with solar batteries Telstar's surface has seventy-two facets, or faces, and thirty-six of these mount solar batteries so arranged that some are always facing the sun

Some years ago experts in the Signal Corps suggested a regular tetrahedron as the simplest geometric form that would fill this requirement, and Space Technology Laboratories has built just such a satellite The tiny vehicle only four inches along its longest dimension and weighing but one pound is designed for simple instrumented research tasks A further advantage of this over-design philosophy is that while one face is directed toward the sun the other three are directed away from it and can thus radiate excess heat as required to keep the solar batteries at the optimum operational temperature

As pointed out the other methods of generating electricity by using the sun s heat on thermocouples thermionic diodes or as fuel to drive a thermal mechanical power plant require much more accurate orientation A single degree of error in a thermionic converter s reflecting mirror for example would have the effect of wasting an appreciable amount of power The Explorer and Pioneer satellites pioneered the paddle-wheel idea in which panels are unfolded from the satellite proper on rotating arms which are then oriented toward the sun Strides are being made in the direction of more precise orientation using gyroscopes yo-yo de spin devices solar battery sun sensors and so on Some advanced schemes simply use the sun s heat for this tricky problem

Energy Storage

After so much discussion of concentration and the problem of facing the sun we come to the logical question of what to do with a solar energy device when the sun goes down This is a serious disadvantage of the solar power plant and for constant power output supplementary rechargeable batteries are needed Such systems work excellently, and



Allison Division of General Motors

Machinist polishing pattern for Fresnel reflector for solar space power plant Grooves in this flat mirror approximate conventional parabolic dish

even with the extra weight of nickel cadmium batteries the complete solar power package is competitive on a power-to-weight basis

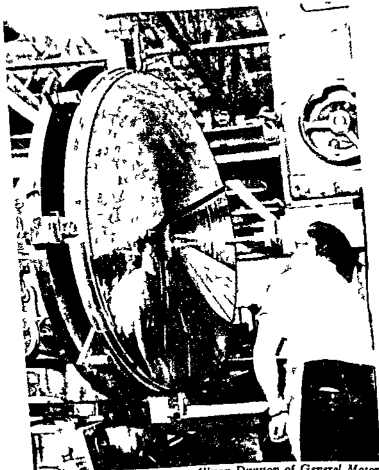
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Other schemes have been proposed including the fuel

cell previously discussed In another, power is stored in a cryogenic or supercold and superconducting coil The Navy is interested in this method which has the advantage of furnishing power in a wide range from fractions of a watt to megawatts There are still a number of problems like weight and size, however, and superconducting coil energy storage is in the experimental stages

There is an intriguing possibility in the use of fuel cells with a solar power plant since experiments show that sun light can break down water into hydrogen and oxygen, the fuels used in one kind of fuel cell Such a system would permit energy storage until the hydrogen and oxygen were later combined to produce electricity—and water—to be broken down again by the sunlight

Rather than storing energy as electricity, the solar thermal mechanical engines store it as heat, thus saving wasteful intermediate steps Compounds like lithium hy dride with high specific heats are used to retain the heat generated by the sun so that it can later be converted into electricity needed during the dark period of the orbit

Stand In for the Sun

An important development in the use of solar energy is that of the simulation of conditions in space Early solar batteries were designed for efficient operation on the earth, and the first use of the new invention was as a power source for rural telephone lines After a large number of batteries were launched into space research was conducted to see why their conversion efficiency did not live up to expecta tions The answer was simple The light in deep space was different from that filtered through our atmosphere

Solar simulators were built arrays of bright lights with filters that matched the sun s radiation hundreds of miles out

in space Tungsten light sources were used and new solar batteries more sensitive to the blue part of the spectrum were developed These tailored 'blue cells" did the trick Besides the light of the sun, simulators duplicated the airless cold of space, and solar batteries were tested not in earth s atmosphere as previously, but at "air mass zero" Ways were found too, for filtering out much of the heat that degraded the battery's performance, and for dissipating that still received by the battery In a vacuum, of course such unwanted heat can be removed only by radiation, instead of the easier convection and conduction cooling possible on earth

A number of firms, including Bausch and Lomb, build solar simulators and the testing of space vehicles is now a relatively easy matter The jet propulsion laboratory at California Institute of Technology operates a simulator 80 feet high and NASA plans one for its Houston facility 105 feet high Solar panels intended to operate near Venus where the solar constant is far more than tnat of earth can be accurately evaluated before they make the long trip into space And for Mars, farther out and receiving only about half the energy available at earth, designers are learning how much additional panel area is needed

More Power to Us

Despite a rather lengthy history in literature—mostly fictional—space power systems are actually only a few years old Some remarkable breakthroughs have been made, though, to name the solar battery and the Battelle Stirling-cycle engine as examples There may well be others imminent that will make obsolete the best things we have on drawing boards today

One scheme is that of powering satellites flying at altitudes of sixty to seventy miles with the chemical energy

trapped in the ionosphere This exotic use of solar fuel is based on the fact that the sun has turned the ionosphere into what amounts to a huge storage battery Sunlight at this altitude has broken down the usual form of oxygen or O_2, to atomic oxygen which is a single form of the element In 1956 the ionosphere s supply of atomic oxygen was demonstrated dramatically when a rocket delivered eighteen pounds of nitric oxide to that altitude This triggered a million candlepower burst of light as atomic oxygen was recombined Using a suitable catalyst and a heat exchanger some scientists feel that a satellite could be powered by this stored solar energy

An interesting solar conversion method has been suggested by engineers of The Boeing Company a solar battery that not only converts sunlight to power, but stores it as well Their process a photochemical one shows theoretical conversion factors approaching 100 per cent Other researchers are working with organic dyes to make low-cost batteries We will investigate the possibilities of photochemistry in a later chapter

There is one avenue as yet largely unexplored one that might get around the storage problem for the solar battery First of all during daylight the earth re radiates sunlight in an amount approximating 20 per cent of what it receives It is possible that this radiation could be converted to electricity by solar batteries facing earth instead of the sun Secondly and with more potential perhaps the earth radiates infrared energy in the amount of about 280 watts per square meter again almost 20 per cent of the solar constant Added to the reflected sunlight this energy boosts the potential at 300 miles above the earth s surface to almost 40 per cent more than the value usually considered And the infrared energy is radiated not just during sunlight but constantly Thus while a satellite is orbiting in the dark its standard

solar batteries so much dead weight, there is a steady source of infrared that special cells might convert into electricity

As we have noted, it is early yet to tell exactly how the quest for power in space will be resolved There are some obvious guidelines, but the best solution may well be an exotic approach still vague in the brain of a scientist Ever clearer, however, is the fact that scientists will succeed in the magic of pulling power right out of the air—or the vacuum of space as the case may be

as the theoretical maximum for their new device, an outgrowth of work with semiconductors particularly in the transistor field Within a year they had doubled the efficiency of the early cells and were producing about 11 per cent efficiency with the solar batteries they were also proving their feasibility in an application providing power for a rural telephone line in Georgia Interestingly, the efficiency of a gasoline engine is in the neighborhood of the 11 per cent figure

In the years since, the figure has crept slowly upward toward the maximum, with some in the industry claimed to give 14 per cent efficiency and rumors of freak cells yielding as high as 18 per cent William Shockley, who pioneered the transistor, is currently working toward minimizing of the factors limiting efficiency and he suggests that 30 per cent may be the actual limit. With such a high conversion potential it would seem that the solar battery's mechanism might be complex in the extreme and its operation of a rather sophisticated nature The opposite is true The solar battery simply sits quietly in the sun instantaneously turning its rays into electricity So simple is the solar battery that hundreds of youngsters have made their own using silicon wafers supplied by the International Rectifier Corporation, chemically treating them and heating them in small furnaces *More recently Bell Telephone Laboratories has made avail*able a complete kit for this purpose The solar battery has no moving parts except for the electrons or holes that constitute the flow of current, and it apparently never wears out It is in short something that approaches the perfect conversion device—light in weight efficient reliable and long lived Even at a price of thirty dollars a square inch it is the biggest power bargain available for some applications notably those in space For example a 5 per cent solar battery operating for a little over a year delivers power more *cheaply than flashlight batteries!*

As we have said, the solar battery is made of semiconductor material, a semiconductor being a substance with properties between those of a conductor and an insulator This phenomenon is exploited to make the semiconductor diode or rectifier, and also the transistor, which operates in



The Boeing Company

The vertical mirrors on this solar battery panel effectively double its output by increasing the amount of sunlight striking the batteries themselves This technique cuts cost and weight of space power supply

a manner analogous to the vacuum tube The silicon material is much the same for transistors as for solar batteries though the latter do not require as high a grade

Since silicon is sand, and sand the most plentiful material on earth, solar batteries might seem cheap with respect to their raw material Unfortunately it is a long and expensive route from raw sand to the 'single crystal ingot drawn

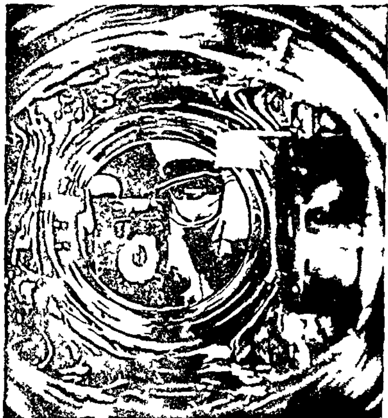
from a white hot furnace, the single crystal necessary for the vital semiconductor action Processing the silicon thus brings its cost up to hundreds of dollars a pound

Wafers of silicon are sliced from the ingot and polished smooth Then an impurity is deposited on its surface Generally boron, this impurity creates a layer of p (for positive) material, while the parent silicon wafer is 'n (for negative) material This sandwich forms the familiar 'p n junction that is the heart of transistor and solar battery alike The layers are also called "acceptor and donor That is the p layer accepts electrons, and the n layer gives them up, to accomplish the flow of current

A properly made solar battery when exposed to light experiences a flow of electrons from one layer to the other, these electrons are driven by the light striking them All that remains is to attach conducting wires to the p and n layers and we have a source of power that will play a radio drive a motor, or charge a storage battery Early solar batteries were round just as the wafers were sawed from the ingot Today most are rectangular standardized to dimensions of 1 by 2 centimeters and 40 millimeters thick A single cell weighs only two grams and develops an output in milliwatts at approximately half a volt Just as flashlight batteries may be hooked together to give more power solar batteries can be connected in series to raise the voltage, or in parallel to yield more current Shingled' modules of five cells give about a two volt rating, twenty eight-volt panels are fairly common in space power applications

The silicon solar battery has improved over the years in many respects In one technique called gridding additional metal contacts are formed on the silicon to help carry the current This reduces internal resistance and results not only in higher conversion efficiency but in higher voltage output as well

which were to be used under a similar light source While early attempts were made to simulate the sun with tungsten light, it was evident that the results were not satisfactory



U.S Army Signal Corps

Testing a new radiation resistant n on p solar battery Such improved designs can withstand ten times more harmful radiation in space than earlier models

One harassed engineer spoke out at a meeting on standardization of solar batteries to the effect that the only guarantee of performance would be to send the tungsten light out into

space with solar batteries Happily the reverse was accomplished by using better simulators which in effect brought the sun down to earth New batteries were designed to respond more to the blue end of the spectrum prevalent in space and thus yield more efficiency, as mentioned earlier

Despite all these improvements there remains one serious drawback to the silicon solar battery It is very expensive Present costs range from one hundred to three hundred dollars a watt, and thus it is practical only for limited applications such as space vehicles Early publicity on the solar battery included optimistic descriptions of homes roofed with solar shingles supplying sufficient power for all household needs As yet no one has been able to afford the several-hundred thousand dollars such a roofing job would cost, but much research is being done to lower the price of solar batteries

Other materials than silicon have been used Gallium arsenide was one of the first however it is even more costly than silicon and seems to have application only in high-temperature scientific projects A more promising material is cadmium sulfide, and solar cells with efficiencies approaching 5 per cent have been made with this material It is particularly interesting that fairly large area cells, up to three inches square, have been produced Obviously a large part of the cost of a sizable solar panel is in the assembly of hundreds or thousands of carefully matched cells So workers with cadmium sulfide and other materials are looking for techniques which will permit production of large area cells

Several such methods exist Thin films' can be deposited by vapor methods spraying, and so forth, and some results have been achieved For example selenium cells six inches square have been produced commercially though at efficiencies of less than 1 per cent Tiny spheres of silicon have

been embedded in plastic to make solar batteries as large as one inch by three inches and experimental work has been done in rolling silicon into thin sheets for making large-area batteries Thus far the rolling technique has not proved practical and better results have been obtained with the growing of ' dendritic or whisker-like crystals Solar batteries a foot long have been produced from these dendrites of silicon, and raw crystals grown in lengths of up to thirty feet The principle of operation of a solar battery made from cadmium sulfide is different from one made of silicon Also the material used in some experiments is transparent and can intercept light from all directions

Proceeding from the inorganic materials, researchers are also doing work with solar batteries of an organic nature Various dyes have been used with some success, and the potential here is a low efficiency but very low cost battery producible in large areas Optimism prevails and some researchers are talking in terms of one dollar to ten dollars per square foot of surface When that day comes, we *will* be able to roof our homes with solar shingles!

Thermoelectricity

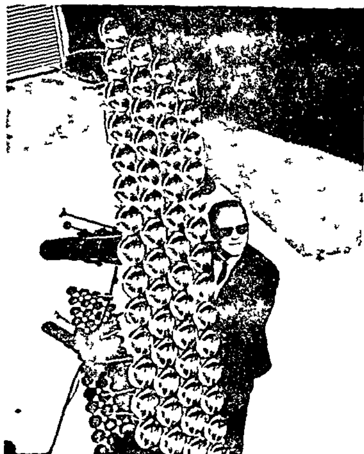
While the solar battery then is the simplest, most direct conversion route from sunlight to electric power, it is not the only direct conversion method Next let s discuss that of thermoelectric conversion the changing of the sun s *heat* into electricity The discovery of thermoelectric conversion dates back to the Seebeck effect in 1822 when a German physicist by that name experimented with heat and magnetism in various materials Unfortunately Seebeck did not believe what was actually happening in his experiment namely that heat applied to a junction between two metals

was producing electricity It remained for others to spell out what Seebeck had stumbled onto, but today most of us are familiar with the thermocouple Furnace controls are an excellent example A thermostat to regulate a gas furnace needs a current of electricity, originally supplied by conventional means from house wiring The idea of inserting a thermocouple into the pilot flame on the burner was developed and thermoelectricity generated sufficient current to operate the controls without the necessity of connecting to the house wiring and adding a transformer

The recent flowering of thermoelectricity, like the solar battery, owes itself to the development of semiconductor materials Pioneer attempts at thermocouples yielded efficiencies of 1 per cent or less Today materials like lead telluride and zinc antimony produce power at 10 per cent efficiency and theoretically can do much better What is needed in the thermocouple is a high ' Seebeck coefficient", that is, a high ratio of power generation to electrical resistivity and thermal conductivity

The materials mentioned above are binary alloys that is, they have two components Ternary and even quaternary systems are being used, silver-antimony telluride for example, and Neelium which is composed of bismuth, tellurium selenium and antimony

Direct sunlight is not sufficient to heat the junctions of thermoelectric thermocouples properly, so some means of boosting the heat is needed Several fold increase is sufficient, and temperatures of 600 degrees are being used successfully The greater the heat the greater the power available however, thermoelectric materials function efficiently only to certain temperatures after which their performance begins to be sharply degraded A maximum of about 1,000° C holds for most materials though experimental work is being done at higher temperatures Mixed



Ham lton Standard D v s on of Un ted A rcraft

The small alum num reflectors focus solar energy on thermocouples to generate power in this thermoelectric generator for Air Force use in space veh cles

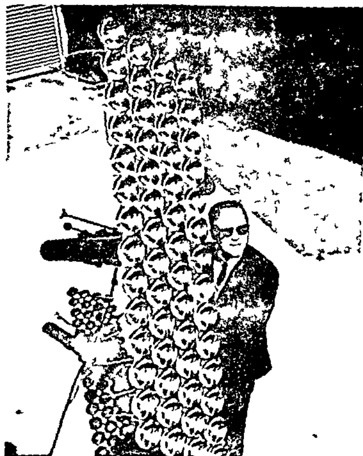
valence compounds of the transition metals samarium sulfide for example perform well at 1 100° C

With the solar battery such a simple device why do we spend time and money on developing thermoelectric converters which seem far more complicated? For instance

while solar batteries perform excellently without any kind of concentrators, the thermocouple is generally useless in the unfocused rays of the sun The problem of waste heat, and maintaining sufficient temperature difference between the hot and cold ends of the thermocouple further complicate the picture But there is good reason for all the effort expended One is economic A square yard of solar batteries might cost in the neighborhood of fifteen thousand dollars, exclusive of the cost of assembling them into a usable panel In the thermoelectric converter, a solar collector with a yard of area focuses this much sunlight onto thermocouples only a few inches in diameter resulting in a great saving of expensive converter material Since not as many wiring connections are needed, the reliability of the system increases And radioactive and other high energy radiation is not as harmful to the thermoelectric converter as to the solar battery

Present work with thermoelectricity was sparked in Russia, even before the boost given by the developing semiconductor technology In the early 1930 s, Dr Abram Ioffe pioneered the field, predicting an efficiency of 4 per cent for materials then available The results were liquid-fueled thermoelectric generators powering radios and other electrical equipment in outlying areas Thermoelectric refrigerators were produced commercially in 1953 And in 1956 Ioffe developed solar powered 40- and 100-watt thermoelectric converters

In the United States, Westinghouse has produced liquid-fueled thermoelectric converters in sizes up to five kilowatts for the U S Navy The Atomic Energy Commission contracted with the Martin Company and the Minnesota Mining and Manufacturing Company for the SNAP nuclear generators, in which radioactive polonium 210 furnishes the heat for a thermoelectric converter SNAP III produced



Hamilton Standard Division of United Aircraft

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more than five watts at an efficiency of about 5 5 per cent and a total weight of only five pounds for the first space application of thermoelectric power (It was SNAP III that caused a controversy when it was placed on the President s desk) SNAP I-A a larger converter uses polonium cerium 144 and produces 125 watts More recently, Hamilton Standard Division of United Aircraft has developed a solar thermoelectric plant for Wright Air Development Division This system uses some 900 small aluminum reflectors in a panel of 100 square feet to develop 100 watts of power This capacity will eventually be increased to 1 500 watts

In addition to its work with liquid fuel thermoelectric converters Westinghouse has also built units for solar power using an 8 foot reflector to focus sunlight on a bank of 32 thermocouples Such a plant can develop 125 watts at about 4 volts and Westinghouse estimates the cost of producing electric power at from 7 to 10 cents per kilowatt-hour, making such a system attractive even in areas less remote than space

The General Atomic Division of General Dynamics is another contender in the race for a solar thermoelectric power plant Using a thin sandwich' of metallic sheets about an eighth of an inch thick, the General Atomic design is expected to provide a kilowatt of power for as little weight as twenty pounds

A distinct advantage of thermoelectricity over the solar battery is that hundreds of firms are working with thermo electric materials compared with the handful producing solar batteries The reason is simply that just about any heat source will operate a thermoelectric junction while the same is not true for the solar battery Solar thermoelectricity may well surpass the solar battery soon and find wide application both in space and on earth

Thermionic Conversion

We come now to a third method of converting solar energy directly to electricity—that of thermionic conversion As mentioned earlier, this method entails the emission of electrons from a cathode to an anode, so that the unit is generally referred to as a thermionic diode Thermionic emission is the basis of operation of most vacuum tubes

Thermionic conversion is the most complex of the three methods, it is also the newest The phenomenon was noticed by Edison years ago in his incandescent light bulb, but it was not until recently that commercial units were available Predicted in 1957 and developed in the following years by General Electric, the first converters were the size of a silver dollar and produced one watt of electricity

The principle of thermionic conversion is simple enough The application of heat to a cathode causes the emission of electrons and the generation of electric current The major problem encountered concerns the 'space charge" phenomenon a cloud of negatively charged ions that hinders the free flow of electrons from cathode to anode There are three general methods of fighting this space charge, and thermionic converters are built as vacuum diodes gas diodes or magnetic triodes

In the vacuum diode, the electrodes are placed very close to each other to minimize the space charge Dimensions required are measured in fractions of thousandths of an inch Introduction of a gas rather than a vacuum in the diode chamber has also been found helpful in canceling the negative space charge Cesium vapor is the gas most often used, and it has the added advantage of reducing the 'work function' of the anode, thus boosting the flow of current

The magnetic triode is an attempt to use magnetic fields

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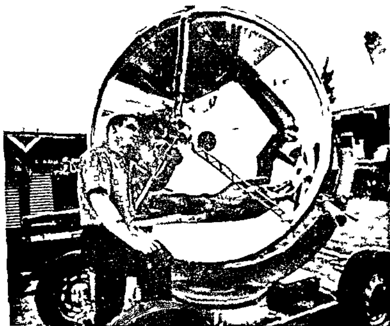
to nullify or reduce the space charge Work in this direction is largely experimental, and most converters are of the close spaced vacuum or the cesium vapor-cavity type Both have been produced under contract for the government and in 1960 the Tapco Group of Thompson Ramo Wooldridge Inc, delivered converters of each type for evaluation Each converter delivered 250 watts of power at 28 volts

While the technology required for building the thermionic converter is more demanding than either thermoelectric or photovoltaic approaches to power generation it offers advantages over both Present materials and techniques show a top efficiency of about 15 per cent, but expected advances in the next decade or so could raise this to perhaps 40 per cent Some authorities consider it feasible even now to build a solar thermionic converter which will deliver a much higher ratio of power to weight than that offered by any other system And plants delivering as much as fifty kilowatts are felt to be practicable for space applications'

General Electric received an Air Force contract in 1960 for development of a 500-watt thermionic converter using solar energy More recently the company has developed the STEPS, or Solar Thermionic Electrical Power System for the Air Force Possible applications are listed as manned spacecraft, lunar colonies communication satellites, and smaller vehicles The STEPS plant includes an array of 105 thermionic diodes with heat delivered by a sixteen foot folding parabolic mirror and associated equipment for pointing the mirror constantly at the sun Early in 1962 the STEPS converter actually produced electrical power from the sun at the company's facility on the desert near Phoenix Arizona

The thermionic converter requires temperatures higher than the thermoelectric converter for its operation temperatures ranging from 1,100 to 2 600° C. High-quality elec

trodes such as tungsten and nickel are necessary, and the high temperatures gradually evaporate away the cathode The thermionic converter thus does not have the life span of the solar battery, or even the thermoelectric converter, however, it is felt that improved designs and new materials



Electro Optical Systems Inc

Engineer points to thermionic generator at focus of lightweight mirror This solar power plant was developed for a NASA Mars probe

will increase its life An added advantage is its use in a solar probe since its higher temperature operation would permit closer excursions than would the solar battery with its top temperature of something like 175° F or the thermoelectric at about 1,000° C

An unusual possible use of the thermionic converter is

thermionic converter depends on the temperature difference between cathode and anode If we heat the cathode to 2,000 degrees and the anode to 1 000 K we may have an efficiency of 50 per cent Naturally the anode tends to become hotter than 1,000 degrees On earth we may cool it in a number of ways conduction convection and radiation In space, however only radiation is available to us So we must provide fins suitable for radiating away the waste heat

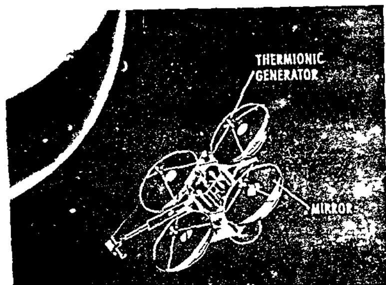
One clever solution to this problem has been effected by the Minnesota Mining and Manufacturing Company and Thermo Electron Engineering Corporation, in cascading thermionic and thermoelectric converters The thermionic converter accepts heat at 1 440° C at its cathode The anode rejects waste heat at 500° C not to the atmosphere or to space but to the cathode of a thermoelectric converter' There is a double reward in this cascading technique in that the original heat is used twice boosting both output and efficiency of the composite unit the final waste heat is at a much lower temperature which simplifies the problem of cooling the anode

Other Systems

While we have discussed the major direct conversion methods there are of course some others Magnetohydro dynamics has been mentioned and solar powered MHD space power plants are proposed Ion propulsion uses electric power and solar energy is a logical contender for the job Republic Aviation has already built a small plasma pinch engine that can be sun powered for example The storage of electrical energy as cryogenic magnetism to be drawn on slowly or in fantastic bursts of power for short duration is under investigation by United States Navy scientists and others as mentioned earlier

There is another kind of converter that changes sunlight

into electricity This is the photoemissive converter, and it works in a manner similar to the thermionic converter except that it is unconcentrated light rather than heat, which causes electron flow As photons of light strike a suitable photoelectric surface, they dislodge electrons from the



National Aeronautics & Space Administration

Artist s drawing of solar thermionic power system An array of four mirrors furnishes power to thermionic generators at the focal points.

cathode which then flow to the anode causing an electric current Einstein s photoelectric law theorized on the photo emissive effect in 1905 and in 1916 Millikan proved the accuracy of Einstein s predictions with actual experiments However, exploitation since then has been quite slow

The advantages of the photoemissive converter are obvious since no concentration of sunlight is needed but there are problems with the method too Some of these are the same as in the thermionic converter, for example space

charge hampers operation and must be dealt with by close spacing or the introduction of a vapor like cesium

The United States Army Signal Research and Development Laboratories have built experimental photoemissive solar converters which prove the feasibility of the idea While the efficiency of the test models is quite low work indicates that 2 per cent converters should be competitive with solar batteries on a cost and weight basis USASRDL estimates that a watt of photoemissive electricity will cost about thirty dollars compared with about one hundred dollars for solar batteries and that eighteen watts per pound may be expected

Since its operation is static, long lived, and basically simple photoemission seems excellent for space power applications Dr Thomas Gold of Cornell University has suggested large area plastic sheets generating electricity through the photoemissive effect Even at relatively low conversion efficiency such lightweight sheets are attractive and cost and weight figures should be very low Gold suggests the possibility of developing a kilowatt of power for a kilogram of converter weight This is roughly two-thirds horsepower per pound a ratio which rivals the aircraft engine And since a plastic sheet could be rolled easily for storage there is further advantage to the system

On a more ambitious scale, a Martin scientist has proposed a lunar power station consisting of acres of nets of photoconverters generating the megawatts needed for a large moon base Such a power plant may ultimately benefit us stay on-earths too

Summary

Man has come some distance down the road from his first use of heat energy, and today most of his needs are not for

heat as such but for electricity Happily the conversion of heat and light to electricity can be accomplished directly Thus a gasoline flame or the heat from a radioactive pellet can be changed through the magic of thermoelectricity or thermionics to instant electricity for running a multitude of devices we have come to rely on Even more fortunate, the heat or light of the sun can do the same task Long after the last of the shale oil is burned, and even when the last atomic fuels are expended, there will still be solar energy available for conversion to electricity

5

Steam Engine in the Sky

The solar paddle wheels on the Pioneer satellite have sometimes given the erroneous impression that the sun's energy was actually churning the probe through deep space much like an up to date version of a Mississippi side-wheeler Although an even more fanciful concept may soon be propelling space vehicles solar paddle wheels unfortunately do no paddling at all In fact solar batteries may be too expensive to be used as propulsive power for any sizable spacecraft

It is true that many thousands of solar batteries have been stacked up to provide hundreds of watts of power for communication driving small equipment motors and the like But to generate kilowatts of power in this manner will be very costly A proposed four kilowatt power plant of solar batteries would cost millions of dollars and as we progress to greater power the necessary panels quickly become not only priceless but unwieldy as well As space vehicles be

come bigger and more sophisticated, with greater power requirements designers are turning to other solar energy devices than batteries Since the use of solar heat for *indirect* conversion to electrical power looks very attractive we will soon be launching steam engines into space!

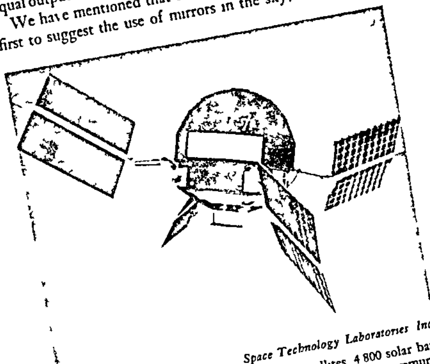
We are all familiar with the sun's heat, stay too long at the beach and the result may be a painful burn Roll up the windows of your car on a hot day and you create a solar oven of sorts And what feature writer in need of inspiration hasn t used the frying of an egg on the railroad tracks to fill space? Unwittingly we make more use of solar heat than we realize since it warms our houses in winter Unfortunately it warms them even more in the summer but we will not pursue this thought at the moment

A simple economical solar reflector can deliver as much as half the available energy to its focal point This represents an efficiency of 50 per cent, and better reflectors as in the case of the SET system yield rates of more than 80 per cent Let us move out to space for a moment, and see what this means Eighty per cent of the available 1 400 watts for each square meter represents more than a kilowatt of power And a kilowatt, remember is more than one horsepower Thus for each yard or so of area we can collect heat worth one horsepower in the market Of course, unless we are heating a house, or frying eggs heat energy is not particularly attractive to us, we must convert it into some other more practical form This is generally electricity But today the turboelectric generator, using heat as a source is the most efficient converter known running at rates which in some cases approach 50 per cent Thus with heat collector efficiency of 80 per cent and electrical conversion 50 per cent of that we still end up with about one-half horsepower for each yard of collector area

An overall conversion efficiency of 40 per cent is cer-

tainly a target to shoot at, particularly since initial costs might be kept lower than those of a solar battery panel of equal output

We have mentioned that the German writer Oberth was first to suggest the use of mirrors in the sky, and his ideas



Space Technology Laboratories Inc

Explorer VI the first of the paddlewheel satellites 4 800 solar batteries on the paddles powered Explorer s radio gear for communicating with earth

ranged from fantastic to prophetic The first practical proposal for a solar space power plant was put forth by an Austrian named Noordung This gentleman proposed a space station some 22 000 miles from the earth in a twenty four hour or stationary orbit His ideas were actually predictions and included wheel shaped slowly spinning living

quarters to provide artificial gravity He also designed a power plant in the form of a parabolic mirror focusing the sun s rays onto boiler tubes Electricity was to be generated for immediate use, and for storage during dark periods Since this concept was advanced in 1929 we must credit Noordung with much foresight

More recently, space authority Wernher von Braun designed a space station for the Mars Project concept His book published in 1952 describes a wheel-shaped vehicle, also with a large parabolic mirror for concentrating sunlight on a boiler

Certainly not all authorities have agreed with the solar power plant idea Willy Ley, a recognized expert in the field, announced in a book called *Rockets, Missiles, and Space Travel*, published at about the time the first satellites were beginning to venture into space, that 'the power will not be derived from the sun as was originally visualized,' because a solar plant would simply be too heavy Our government apparently does not agree with Ley entirely, and so today we have a number of solar-powered mechanical plants under development, and in only one major respect do they differ from fanciful early proposals The boilers of these solar engines will contain not steam but mercury, rubidium vapor, or some other exotic fluid because of the different environment encountered in space

With the exception of the vacuum and no gravity conditions of space and the means of heating the boiler, the design of space power plants, like that of terrestrial applications, is a job for the thermodynamicist and mechanical engineer Some years ago government agencies contracted for research and development work on a number of thermal mechanical plants to furnish power for space vehicles, as it had been demonstrated that these were going to work and would need a source of electrical power

Sunflower

Prior to 1960 the Tapco Group of Thompson Ramo Wooldridge Inc had proved the feasibility of a unit called SPUD a one kilowatt Solar Power Unit Demonstrator The prototype ran successfully for 2,500 hours, and TRW got another contract for Sunflower, a three kilowatt plant that could fit into Saturn and other boosters The concept fea tured an unfurling thirty two foot mirror a mercury boiler and a Rankine cycle turbogenerator

Designed to operate in space for a minimum of one year, Sunflower is expected to be available by the middle of 1964 As a space power system it will be folded and packed into the nose of the launch vehicle In orbit the petals of Sun flower will open and latch into place Once the aluminum reflector has opened the power conversion system will be at its focal point some twenty feet from the reflector With the solar reflector properly pointed toward the sun prob- ably by an inertia wheel system collected heat will be con centrated on the liquid mercury in the boiler The heated mercury vaporizes and will then drive a thirty pound turbo- generator to produce the three kilowatts of electricity This turbogenerator is a modified version of that used in the nuclear powered SNAP II space engine

After driving the turbogenerator the mercury flows through a large condenser-radiator which radiates heat into space to liquefy the vapor for return to the boiler Since Sunflower will be in the shade for part of the time provision is also made for storing energy in the form of heat

As we have seen the matter of power storage is very im- portant and in some cases more than doubles the weight of the complete power system While the solar thermal mechanical engine converts heat to electricity it can also

store part of the heat for later conversion This seems to be a simpler, lighter, and more efficient method than storing electricity and much work is being devoted to perfecting it

There are several ways of storing heat, but the "heat of fusion' method is most efficient An early application was made in MIT's solar house when containers of Glauber's salt were used as the heat storage medium The advantage of this method is that certain materials require a great deal of heat to melt them and thus absorb and store a large amount of heat per pound As the substance resolidifies, it gives off the stored heat Lithium hydride is used in space applications since it has the highest known heat of fusion This compound can store more than three hundred watt hours per pound, compared with about twenty watt-hours for the rechargeable batteries now used Thus a storage system weighing only a fraction of earlier designs is possible

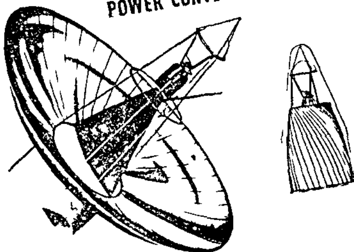
Despite the size and complexity of Sunflower, this pioneer solar space power plant will weigh only about seven hundred pounds We accep revolutionary concepts like Sunflower so readily today that perhaps we miss the accomplishment such a power plant represents In addition to the problems of vacuum and the lack of gravity mentioned earlier, the space plant is subjec to the strain of alternate heating and cooling as it passes from light to shadow Also the problem of lubrication of a high speed turbogenerator is compounded in space since ordinary technique are not satisfactory The generator has therefore been redesigned to simplify lubrication requirements

Hot Air and Sunshine

The idea of running an engine on sunbeams is apt to be dismissed as a lot of hot air, and in one case at least, this is a very accurate appraisal One of the most advanced of the

space engines presently being built is based on the invention of Robert Stirling back in 1816

Although Dr Stirling was a minister, it is quite obvious that his interests were not confined to his pulpit At the age of twenty-six he invented an engine based on what has



National Aeronautics & Space Administration

Sunflower 3 kilowatt solar powered space engine Mirror folds as shown at right for launch unfurls in orbit and seeks the sun

come to be called the Stirling cycle Paradoxically despite the amazing efficiency of the latest hot air engine it cannot be described as revolutionary because Stirling antedated the formalizing of thermodynamics His engine was produced eight years before Nicolas Sadi Carnot presented his classic paper on the efficiency of heat engines

Only twenty eight himself when he in effect founded

modern thermodynamics, Carnot stated that no heat engine can be 100 per cent efficient, since some heat is always wasted Joule, Kelvin, and others went on to develop the theories that Carnot had initiated, but Stirling was not hampered by any of Carnot's laws

We are all familiar with the internal combustion" engine Stirling s hot-air engine was an "external combustion engine in which heated air expanded outside the cylinder, rather than within it The Stirling engine also had a regenerator that 'saved" heat from one cycle to the next Theoretically it had an efficiency of 100 per cent

Thermodynamicists today point out that the inventor made some exaggerated claims about the efficiency of his engines, however, we may forgive Stirling for this since the rules had not yet been formulated, much less written down It is a matter of record that his engines *were* more efficient than existing ones, yet, as often happens the Stirling engine owed its wide popularity to a lesser quality In the old days steam boiler explosions killed hundreds of people a year Since there was no boiler needed for the hot-air engine, there was no danger of explosion and it was for this reason that thousands of Stirling engines were sold

This in itself was not bad but somewhere along the line the main advantage of the Stirling engine was dropped The amazing regenerator the young genius had invented was a source of trouble because of material failures so that many engineers simply removed it The resultant trouble free quiet and safe engines satisfied them even if their efficiency was not nearly what Stirling had in mind when he built the prototype Some of these metamorphosed Stirling engines actually operated close to 1 per cent efficiency!

Despite these changes the Stirling engine hung on and as late as 1939 was produced by the Kessler Company in Chicago Of course much had happened in the field of heat

engines in more than a century, and even though some of the hot-air engines continued to operate, they were generally conceded to be obsolete and interesting only historically and theoretically In fact, at about the time the last Stirling was being built, a thermodynamics text had this to say about the hot-air engine

Much work and some very clear thermodynamic thinking was done in the early development of the hot air engine It is worthwhile to know of the principal ones actually built and operated even though they are today obsolete

Over in the Netherlands at about this same time there was a group of engineers curiously digging into every possible idea they could find for engines The N V Philips Laboratories of Eindhoven had decided that even the best engines available at the time were none too good and wanted to develop a truly high efficiency engine So eager were they that they even resurrected the old Stirling cycle, the obsolete 'external combustion engine And in the years that followed they did some amazing things that would have gladdened Stirling's heart

By 1958 Philips was producing a variety of Stirling cycle engines that delivered power at claimed efficiencies up to 40 per cent a figure which while not close to the 100 per cent theoretical maximum was still far better than most engines Along with high efficiency went the other advantages of safety and quiet operation Internal combustion engineers actually consider the Stirling engine eerily quiet In 1958 remember Vanguard I and its pioneer solar cells went into orbit And that year General Motors Allison Division signed an agreement with N V Philips Laboratories for further development of the Stirling engine including a three kilowatt solar powered space engine for NASA

The Allison space engine will produce the same amount of power as TRW s Sunflower For use in space the Stirling

engine has undergone some changes from its land-based counterparts First the engine must be sealed for operation in the vacuum of space In addition the working medium is



Battelle Memorial Institute

James A Eibling studies model of Stirling cycle solar engine A version of this engine is being built for use in space

not air but helium or perhaps hydrogen In place of the Sunflower s thirty two foot parabolic mirror the Allison engine relies on a nineteen-foot flat Fresnel reflector which

The entire engine is packaged for launching in a cylinder about 8 feet in diameter and 7 feet long The large curved mirror is erected with the technique described in Chapter 3 Once in orbit a plastic balloon packed in the cylinder is inflated and the 42 foot section adjacent to the engine is formed into a parabolic shape and stiffened with foam Next a hot wire burns off the unwanted portion of the balloon and this is blown away Now the mirror is extended on telescoping arms until it is the proper distance from the cav ity which traps solar heat, orientation toward the sun is accomplished, and the engine begins operation

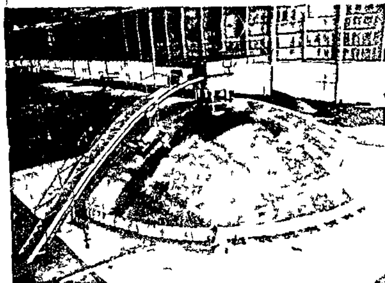
An idea of how much power 15 kilowatts represents can be gained from studying your electric bill A typical home might use about 1,400 kilowatt hours a month, or two con tinuous kilowatts, so a 15-kilowatt plant would serve seven or eight homes on your block Obviously a 15 kilowatt power plant in the sky can deliver power for a good many uses—there are lots of little foreign cars driving about with no more power than the equivalent of 15 kilowatts[1]

Earlier we compared the solar battery approach with other methods of powering a 100 watt space probe of Mars Now it will be helpful to use the same technique in evalu ating the various solar energy approaches to find out which is the most attractive Moving from the modest 100-watt power plant to one of 3,000 watts or 3 kilowatts it is in teresting to see that the solar batteries which came out so well in comparison with more conventional systems here tie for last place with other solar energy conversion methods

Weights are given for a complete power system, includ ing a storage system for power during dark periods controls to orient the solar collector toward the sun, and so on The heaviest system is the thermoelectric at 1,376 pounds Next is our old reliable solar battery method at 1 350 pounds The turbogenerator or Space Age steam engine shows a dra

matic slash in weight to only 848 pounds, and weighing even less than that at 799 is the solar thermionic generator.

Beyond the saving in weight that seems possible with solar power plants other than solar batteries is the saving in dollars. Since thermoelectric, thermionic, and thermal-mechanical generators operate at much higher temperatures



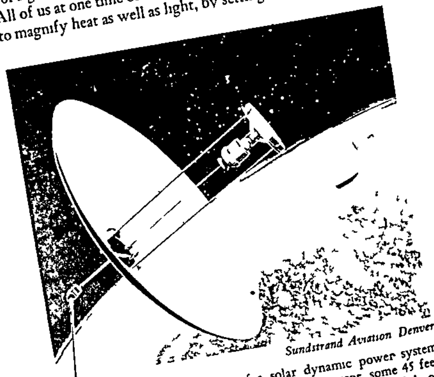
Goodyear Aircraft Corp.

Assembly of 45 foot solar reflector. This inflatable foam rigidized collector is part of the Air Force Advanced Solar Turbo Electric Concept (ASTEC).

the actual converter material is much smaller in dimensions than the solar panel. Instead of a thirty five-foot panel of expensive solar batteries, the other systems use a metal or plastic collector of similar size which costs only a fraction as much. Thus not only can we generate sizable amounts of power with solar energy but we can even *afford* to do it!

Antedating the developmental work of these solar pow

ered mechanical engines were numerous attempts to harness Sol right here on the ground as we shall see in Chapter 10 All of us at one time or another have used a magnifying glass to magnify heat as well as light, by setting fire to kindling or



This is an artist's conception of a solar dynamic power system applied to a space vehicle in earth orbit The mirror some 45 feet in diameter is aimed at the sun and collects solar energy while on the light side of the earth

perhaps burning initials in a plank More than fifty years ago scientists and engineers were building large solar-powered machines to generate power for pumping water and other tasks

The early solar engines were doomed economically because they were not nearly as efficient as their builders

claimed them to be. Even if a patchwork of mirrors or a curved metal collector did manage to focus 25 or 35 per cent of the available heat onto a boiler, this was only the beginning of the attrition. The heat engine itself was of far less efficiency, and friction losses lopped off still more of the waning power. The practical solar engine had to wait for better materials and better design.

The space race has accelerated the development of these requirements, and engineers are already rivaling the efficiency of the admittedly simpler solar battery with thermal mechanical engines. With the goal a tempting figure somewhere near 50 per cent of that available one horsepower per yard of sunlight, engines that "run on sun" are here to stay—in ever increasing numbers.

same motive power Basking in the sunlight, it seems inconceivable that these gentle rays could drive a spaceship weighing many tons on a journey to the moon, much less to the more distant planets Granted that a highly sensitive balance scale can weigh the impact of a flashlight beam, the strength of that beam is still barely perceptible and certainly not in a class with the rocket fuels in use today Hydrogen and liquid oxygen the solid fuels, and other more exotic kinds in prospect, develop energy with an explosive force measured in millions of tons of thrust It is easy for us to visualize harnessed atoms doing prodigious tasks when we recall the huge mushroom clouds, and the devastation atomic bombs have caused

If indeed the only way to make flights into space was by firing a vehicle directly from earth to its target we could immediately rule out solar energy—at least in the direct sense we have been considering up to now—as a contender for the job of fueling such trips Such a cannonball, quick-and dirty approach to space flight is surely possible, but it requires a fantastic amount of power An alternative method is to loft the spaceship into orbit with a smaller explosive charge and then to launch it on its way from this intermediate way-station in space Our first exploration of the moon will most likely be made by a double version of this technique Apollo will be placed in earth orbit and then hurtle for the moon Orbiting the moon, it will dispatch a smaller 'lunar bug' for the actual landing The bug, when its exploration is complete, will blast off the lunar surface, not for earth, but for a lunar orbit rendezvous with Apollo which will then return to earth

Such an approach has another merit besides the economical aspect The big bang shot requires terrific accuracy to hit a target perhaps millions of miles away Use of the orbital technique and a subsequent fresh start on the second

phase permits correcting for any errors made in the first Thus it is possible to save not only fuel but lives as well a fact much appreciated by those who first take the giant step into the empty reaches of space

Incidentally using chemical rockets imposes an additional condition on the spaceship Once the Atlas or Saturn or whatever booster we are using is ignited, the crew does not have the option of throttling back or shutting down and later restarting For maneuvering in space it is preferable to have a more flexible power supply one that can be easily controlled

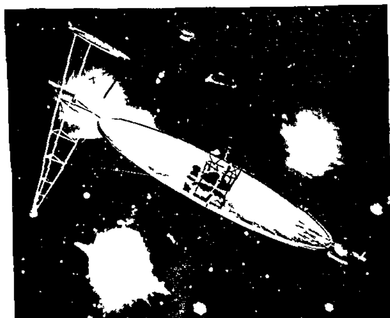
Here is where the use of solar energy—or nuclear energy, of course—comes in Once in orbit our spacecraft can be swung out slowly in an ever-widening circle that will eventually take it where it wants to go in space While it might sound at first hearing that such a long-way-round route would be hopelessly slow and on a par with the milk train or a slow boat to China, actual calculations of trips to other planets with low acceleration propulsion compare surprisingly well with rocket propelled 'straight line' trips

Sun Power for Space Journeys

The notion of space flight is quite old the first lunar voyage having been described in Lucian s *True History*, written in 120 A D A variety of propulsion methods have been used in fanciful tales that followed including even wild swans but it remained for Cyrano de Bergerac to power one of his spaceships with solar energy His *Voyage dans la Lune* and *Histoire des Etats et Empires du Soleil* were written about 1650 and while they are as unscientific as might be expected of a man living before the discoveries of Sir Isaac Newton and James Watt the concept of solar energy is startling

Cyrano also powered one of his craft with rockets apparently covering all possibilities for space flight

Three centuries later, almost to the year, other men began to write about space voyages using power from the sun But these men were not writers of science fiction In 1954 Wil-



The Boeing Company

Model of solar powered Martian Explorer part of The Boeing Company s Program for Astronomical Research and Scientific Ex periments Concerning Space This unmanned vehicle is a prelimi nary design study

liam Conn who had built a number of solar furnaces for laboratories and industrial plants wrote a short note in a scientific journal suggesting the use of a solar collector to focus heat for detonating the rocket fuel of a missile Two years later Krafft Ehricke, a German rocket scientist who had come to the United States delivered a paper titled ' The

Solar Powered Space Ship ' at a meeting of the American Rocket Society Ehricke must be credited with rare courage to appear as a rocket expert before others of his kind and extol the virtues of something so mild as solar energy

Cyrano had journeyed to both sun and moon Ehricke was more scientific in his approach and more modest in his goals The solar-powered craft, he felt, was best fitted for circumlunar or cislunar flights, that is, for trips around the moon and in the space between it and earth Furthermore, Ehricke s solar powered spaceship looked more like a balloon, or rather, two balloons

We have mentioned that weight is the biggest space barrier, and the tug of gravity drains so much power that many experts believe space flights will begin and end at satellites orbiting the earth At this weightless altitude enough fuel can be carried to reach an objective But even departing from such a satellite outpost would not be easy

Ehricke's rocket engine, for example, would carry 11,000 pounds of liquid hydrogen A conventional chemical engine would also require an additional 50,000 pounds of oxygen to be mixed with the hydrogen to drive the spaceship This is where old Sol comes in In the solar engine the sun would heat the hydrogen and produce the driving force Instead of 25 tons of oxygen, there would be only the weight of the solar 'collectors,' a mere half-ton in Ehricke's clever solution to the weight problem

Heating the hydrogen to the required 1 000° K takes considerable energy, and even with every yard of collector surface receiving about 1,400 watts of power, Ehricke found he would need two focusing reflectors, each 128 feet in diameter The size of such reflectors posed a tough engineering feat since building rigid and yet light mirrors of this diameter seemed impossible Fortunately the laws of optics were with the designer A parabolic reflector is the

most perfect concentrator of solar rays, so perfect in fact, that in this case the temperature would be too high Why not, Ehricke figured, make a spherical reflector? This would give the same amount of total heat flux, or energy, but spread it over more area

Next he struck on the idea of using, not an open 'dish' reflector but a full sphere A 128-foot reflector of metal would need so many braces and guy wires as to be impractical But a sphere, say a balloon of light plastic, would support itself

A plastic balloon is hardly a solar collector, but silvering *half* the huge bag made it one Aluminized Mylar, one-thousandth of an inch thick and highly transparent, transmits 90 per cent of the sun's rays, and the metallized hemisphere would reflect them onto the hydrogen heaters with an overall efficiency better than 70 per cent, Ehricke calculated A low pressure of 0 01 pound per square inch would keep the bag in proper shape, and diffusion of the inflating gas through the thin skin would help keep the plastic cool Tiny holes made by cosmic dust should not be damaging larger holes could be patched in flight

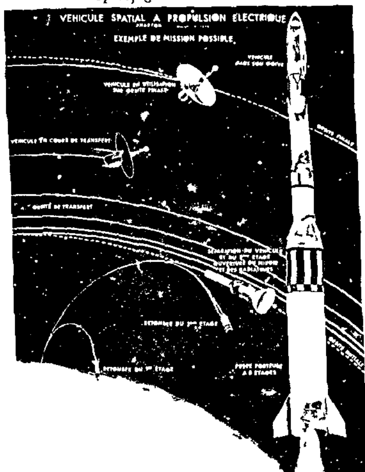
With a gondola for the crew mounted between the balloons, and the rocket motor installed, the total weight for a two-man spaceship would be only 16,000 pounds—about the weight of a fighter plane Two smaller solar collectors would provide electric power for auxiliary equipment The entire assembly would pivot so that the reflectors could face directly toward the sun no matter in which direction the spaceship was moving When it was operating in the shadow of the earth or moon, stored power would, of course, be used in place of solar energy

Ehricke realistically pointed out a number of drawbacks to the solar-driven spaceship First, its acceleration is very low, being only a fraction of that achieved by the chemical

rocket Besides this, control and alignment of such a craft would be quite difficult Maintenance of the plastic bags might also be a problem However, despite the difficulties he felt the weight consideration made solar power very attractive and discussed spheres as large as three hundred feet in size *It is interesting that in the few years since his proposed design* the plastic communication satellite Echo, one hundred feet in diameter has been successfully launched *Designed for an entirely different purpose it nevertheless* demonstrated the feasibility of the solar reflector Ehricke suggested

A large number of solar powered spaceships and probes similar in concept to Ehricke s have reached the drawing board at least, and it seems safe to say that soon one will make good its promise in space One likely prospect is a French satellite called Phaeton after the Greek who was the son of the sun Phaeton is a modest-sized satellite with space traveling ambitions Designed and to be built by the Société d Étude de la Propulsion par Reaction (SEPR for short), it will weigh only about 150 pounds and fold to fit into the nose cone of a standard French three stage rocket SEPR, which has working arrangements with North American Aviation s Rocketdyne Division and the Thiokol Company in the United States selected solar power rather than nuclear because of its relatively low cost

On reaching its initial orbit via rocket booster, Phaeton will spring free of the nose cone and unfold its 13 foot parabolic mirror Its solar power plant is similar to NASA's Sunflower and the larger Sundstrand engines with a mercury boiler and lithium hydride heat storage to give 24 hour operation A 10 cylinder engine develops 2 5 kilowatts of electrical power and this electricity rather than concentrated sunlight is used to heat liquid hydrogen to 3 000° K The hydrogen then passes through nozzles to drive Phaeton



Societe d Étude de la Propulsion par Reaction

Phaeton a solar powered space satellite A turboelectric generator will provide three kilowatts of power to drive the satellite from a low initial orbit to a final very high orbit

into an ever higher orbit Power is also used for the recording instruments that are Phaeton s main purpose In several weeks the satellite is expected to lift itself by its own bootstraps as it were from an altitude of about 400 miles to more

than 22,000, at which position it would be a 24-hour satellite standing still over a spot on the earth

Phaeton's engine differs from the Ehricke proposal in that it is an arc-jet hydrogen rocket, a more sophisticated design necessitating the turbogenerator to convert heat to elec tricity While the arc jet has a higher specific impulse than the simpler solar thermal scheme, the original concept is still attractive enough so that Electro-Optical Systems Inc is making a study of it for the Air Force

The Electric Spaceship

While Ehricke suggested his ship primarily for short trips such as to and from the moon, another ex German scientist had bolder ideas Dr Ernst Stuhlinger proposed a different type of solar-powered craft capable of voyages through outer space This guided missile expert designed a much larger ship propelled by electrostatic force! Tom Swift couldn't have imagined such a craft

Stuhlinger assumed that a large, interplanetary ship would begin its trip from a satellite and land on a like station at the end of the journey Fuel for it would have to be 'ferried from earth to the satellite burning up perhaps 170 pounds of fuel for each pound delivered at the satellite Obviously cost and scarcity of fuel could make long space flights prohibitive

The electrostatic drive uses materials like rubidium and cesium as fuel When these strike an incandescent platinum surface they cause an ion flow which is accelerated by a negatively charged electrode to create an electronic jet or blast This emission creates a tiny force similar to the flow of ions in the television picture tube, and is called electric pro pulsion by scientists and nonsense by the uninitiated

Besides the cesium or rubidium large amounts of electric

power are needed, and for this Stuhlinger would tap the sun His plans showed forty metal reflectors, each fifty feet in diameter, arranged in a butterfly shape about the central section of the craft Obviously such an unwieldly assembly is suitable only for free space, away from strong gravitational pull

The metal reflectors, unlike Ehricke's, were parabolic in shape to generate high temperatures for boilers at each focal point These boilers operated turbogenerators of 200 kilowatts each Stuhlinger pointed out that the large number of reflectors would guard against crippling loss of power in case of meteor hits Another reason, of course, was the difficulty noted by Ehricke in trying to build reflectors of huge size

A colossal 7,500 kilowatts of power would operate the ion drive, with enough surplus for auxiliary equipment such as pumps, and electric and radio gear The ion streams would be emitted from a thousand propulsion chambers arranged in a honeycomb shape

The entire collector was designed to rotate so it could continuously face the sun and individual reflectors spun slowly to aid in circulation of the liquid used in the boilers, anticipation on Stuhlinger s part of the zero-gravity problem

As with the solar ' balloon ' there are disadvantages in the Stuhlinger design It is complex and as a result suffers efficiency losses and is hard to maneuver Stuhlinger hoped that improvements in the solar battery in the future might permit its substitution for the reflectors, boilers, and generators But a solar battery panel producing 7,500 kilowatts is still a mad dream today

Handicapped as it is and with even less acceleration than the Ehricke design an electrostatic spaceship still offered tremendous weight saving that shows up even more in

in seconds Chemical rockets deliver specific impulses up to 450 meaning that 1 pound of fuel will produce 1 pound of thrust for 450 seconds Watching an Atlas, or better yet a Saturn blast off we are awed by the fantastic power displayed yet the rocket's 450-second specific impulse is made pathetic by even the arc-jet to be used in Phaeton Its specific impulse ranges as high as 2 000 And ion propulsion as proposed by Stuhlinger and others ranges up to a fantastic 100 000 some 200 times the efficiency of the best chemical rockets!

Progress in electrostatic propulsion has been slow because we have committed ourselves to a crash program in space Chemical rockets are available and we are using them rather than awaiting development of the electrostatic propulsion that will surely supersede chemical fuels Funding for electric propulsion until now a technological stepchild with only thirty million dollars allocated for 1963 as compared with one hundred and sixty million dollars for chemical and one hundred million dollars for nuclear propulsion will surely increase and the government is planning on solar power for some of these sophisticated space devices Once we accept the idea of using low power for long periods rather than a great big bang all at once we appreciate solar energy It is free and it doesn t weigh an ounce

Solar Sailing

Even hydrogen drives electrostatic engines and other such space propulsion systems pale when compared with what is perhaps the most daring scheme ever proposed—that of solar sailing

Man has known for a long time that sunlight exerts a physical force on objects it impinges upon although not in an amount calculated to set any speed records using photon

impact for propulsion The force exerted by bright sun light is something like one pound per hundred acres, and it was not until 1951 that it was mentioned seriously as power for space flight

When the idea was first broached, hearers were prone to assume that the speaker himself had stood too long in the direct rays of the sun and that photons striking his head had affected his brain However, more and more hardheaded scientists continue not only to discuss the idea but actually to declare it is a workable one

Vindication of the possibility of solar sailing came with the displacement of Vanguard I by the effect of sunlight The tiny six inch sphere, hardly an efficient sail, is moved about a mile in a year according to scientists keeping track of its orbit A mile a year seems pitifully small but sail pro ponents point out that Vanguard s performance at least proves the theory

Solar sailing was first suggested in *Astounding Science Fiction,* but it moved quickly into the learned journals Sci entists at MIT, Sandia Corporation, Lockheed Missiles and Space Division RCA, Westinghouse, Space Technology Laboratories the University of California, and elsewhere in the United States and abroad, proved mathematically that solar sailing was not only possible but highly desirable Just as the electrostatic drive was better than chemical rockets so the solar sail was better than the electrostatic because it had a higher work capacity per unit weight

Briefly, solar sailing is comparable to sailing a boat on water or ice or a windwagon across the prairie On earth molecules of air strike the sail and Newton s laws and aerodynamics take over In space there is no air but Newton's theories have stood up quite well when put to the test If a photon of light strikes a solar sail some of the energy in the light is transferred to the sail While this may seem like

trying to drive a golf ball with a flashlight beam, the basic idea is sound and the implications are of great importance

Man has sailed his boats for three thousand years or more but it was less than a hundred years ago that the theory of the pressure of sunlight was evolved Now the technology has caught up with the principle and many scientists say that solar sailing is not pure science fiction—though surely it makes adventurous subject matter—but a distinct possibility With no embarrassment NASA reports on future space travel talk of solar sailing

One of the men vitally interested in solar sailing is Dr T C Tsu an aerodynamicist at Westinghouse Research Laboratories Dr Tsu describes the familiar technique of placing his proposed vehicle in orbit with conventional rocket power Then however the spacecraft takes on a weird configuration The gondola carrying crew and equip ment unfurls a monster parachute shaped sail of plastic or aluminum foil 1,600 feet in diameter

Dr Tsu makes an interesting comparison of the solar sail approach with the conventional, chemical rocket power method To send a one-ton payload to Mars by rocket all the way would require more than eighty tons of propellant round trip Obviously a thin plastic solar sail even one 1,600 feet across is not going to weigh anything like eighty tons Despite its huge size the sail will weigh only 1,000 pounds and with a good sun can tow a payload of equal weight!

Added to this economic advantage is the fact that a solar sail should be cheaper than any other power plant for space flight It also requires no new knowledge since light high strength plastics are common at low prices today

Even when it comes to speed the solar sail is no slouch as Dr Tsu s figures show While it would take us about 260 days to travel through space from earth to Mars with a big bang chemical rocket power supply the sailing trip de spite a slow start would take only 118 days! Since chemical

rockets can't be started and stopped at the crew s leisure that approach is much less flexible than solar sailing Thus the Mars trip would require an elliptical trajectory and



Westinghouse

Dr T C Tsu and model of his solar sail spacecraft

flight to the far side of the sun and return before reaching our neighbor planet Since the solar sail can be furled or tacked to play sunlight against gravity control in space

is possible, and a more nearly straight line trip could be made And in case we happened to miss the target we would not be doomed to orbit in space, but could perform the spaceman s equivalent of coming about and making an other try Dr Tsu suggests that the very size of the huge sail would make it valuable as a radiation sweeper or perhaps as an antenna for long-range communication

The most important possibility may well be the ultimate speed of the solar sailboat While acceleration is obviously very slow and a hot rodder would die of boredom on a short trip, the speed constantly increases with time The limit would seem to be the speed of light itself in which case the sail would speed along on the crest of the light waves like a surfboarder who knows his business Nautical skippers can sail their boats faster than the wind It might be enlightening to see what happens to the theory that says light is the fastest speed possible, and that no other substance can achieve that 186 000 mile a second rate Scientists are conservative on this point, and cautiously mention speeds of about 2 000 miles per second

If we are alert as we consider this 1 600 foot sail tugging our space capsule along in bright sunlight we will realize that it is another potential source of power—electrical power Schemes for using the photoelectric effect on thin plastic films have been proposed and figures of 'a kilowatt per kilogram' have been quoted as goals Thus our solar sail might also develop many kilowatts for use in operating auxiliary equipment in the space vehicle or for driving an ion propulsion plant

The Sun s Steadying Influence

There are other less dramatic but nevertheless important ways that solar energy can help in space flights Navigation

and the orientation of the space vehicle are examples Both are obviously necessary to the satisfactory completion of a mission There would be little point in sending a probe mil lions of miles into deep space if it did not go where we wanted it to go and point itself in the direction required to do the job at hand The sun can step in here and not only power our spaceships but guide and balance them as well

The notion of thinking big is nowhere more evident than in the breathtaking concepts of our space scientists surely the idea of solar sailing overleaps most space flight proposals Yet this challenging use of the sun s energy seems to have come first and the more routine applications tag along behind A recent paper in the *American Rocket Society Journal* mentions solar sailing proposals and goes on to say that it thus seems reasonable that the pressure from the sun could be used for an attitude stabilization system

The implications are very important when we remember that early satellites simply tumbled through space and thus required far more solar batteries than if they had oriented themselves with respect to the sun By the same token, camera equipped and otherwise instrumented satel lites and probes are worthless unless they aim this equip ment in the proper direction Thus far this orientation has been done with inertial systems using gyroscopes yo yo' weights, and other fairly complex stabilization means Incorporation of a light and inexpensive 'solar sail would obviate the need for a-mechanical system saving weight and money too

Far simpler than a solar sail is the proposal of one scien tist that even a spherical satellite surface can be stabilized by making parts of it reflective and the rest absorptive of solar rays So well established is the business of solar pressure that Goodyear Aircraft has designed a plastic communica tion satellite that is solar pressure proof This clever sphere

maintains a rigidly fixed orbit with no drift caused by the pressure of the sun Once pressurized, the satellite's plastic skin is literally eaten away by sunlight leaving thin ribs that reflect radio waves only

The Solar Compass

Navigation the business of knowing where we've been, where we are, and where we are going gives direction to solar propulsive power, and it is fitting that the sun handle this phase of space travel too Man has long used the sun to navigate about the face of the earth, and the mariner s noonday fix' remains one of the most effective and fool proof position finders available Once we leave the flat of earth though we add another dimension to our navigation problem Position finding in space involves three dimensions and there is another factor to make it tougher than terrestrial navigation—that of the distance scale

On earth go as far as we can we are never much more than 12 000 miles from home base On a voyage to Venus or Mars millions of miles are involved and techniques used on earth fall down Of course we can use long range radio and astronomical triangulation but cumulative errors are likely to result in rather imprecise 'fixes Of great help would be some milestones in space telling us where we are with relation to some absolute base The sun may be the answer

Assuming that it is helpful to know how far our spaceship is from the sun we search for a way to ascertain this dis tance easily The answer is not hard to come by when we recall that the sun radiates its energy in all directions equally, and that energy decreases by a fixed amount defined by the law of inverse squares The farther we are from the sun the less the intensity of its radiation A solar battery for ex

ample, will not produce as much electricity on Mars as on earth because Mars is farther from the sun And here is the secret of our solar navigation system, of course With an accurate radiation measuring instrument, we can tell how far we are from the sun This does not give us our location at a point in space, to be sure, but is somewhat like the information the mariner gets from his noonday observation of the sun The angle he reads in his sextant tells him his latitude, he needs his watch to tell him his longitude So our space navigator will need another reference to combine with his distance from the sun to pinpoint himself in space Earth itself would be a handy reference, and he knows the earth sun distance at all times Measuring the angle between sun and earth, as observed from the spaceship, he can combine this information with the sun distance the radiation instrument gives, and get a "space fix"

The radiation method loses accuracy as the distance from the sun increases, and out as far as Pluto the error could be as large as three and a half million miles This is hardly "pinpoint" navigation Fortunately, for trips to Mars, Venus, and Mercury the accuracy of the solar radiation system is about the diameter of the planets concerned And any navigator who gets within eight thousand miles of Venus should have little difficulty with the remaining distance!

In addition to solar propulsion, stabilization, and navigation the sun is also effective in space communication, as we saw in Chapter 2 In fact, there seems little the sun can't do for the space explorer Fittingly, then solar power may carry us on our journeys about the solar system

7

Earth's Place in the Sun

So far we have focused our attention on solar energy and its uses in the new and booming space frontier. Admittedly this is now the big field for solar energy, it is more glamorous and exciting, as well as more rewarding for the engineer and the manufacturer of solar energy components. There is need for solar energy in space, such a need that if it were not available the entire effort would be seriously hampered. For these reasons solar energy will continue to be exploited most in space applications for some time yet. However, there is another area where solar power will in time be of even greater consequence. Not many of us, even in fifty years, will be journeying into space and needing solar batteries or other such devices. Most of us will remain here on earth. And the greater that number the potentially greater the place of solar energy in our future.

We have talked of dwindling energy supplies, and the factors that accelerate that dwindling, including the wag's prediction that in three hundred years there will be so many of us that standing room only will be the order of the day.

The squeeze is being put on our fading supplies of fuel in two distinct ways First, there are more of us Second, we each require greater amounts of power as time goes on Like increasing taxes the demand for power is an upward curve that is continuously steepening

Once we rode horses to get from here to there, and scrubbed our clothes with a washboard and elbow grease We lit our homes with candles and lamps and when it got hot we simply suffered and complained about it Today the picture has changed and each of us uses thousands of kilowatt hours a year in our homes alone Add to this the amounts of energy we burn up in automobiles, airplanes, factories, and elsewhere and we see a prodigal nation Those Qs of energy with the Q also standing ironically for a question mark, are being cut into ever more rapidly, though some of us say that there will be no pinch in the next century or so Even if true this is an exceedingly short view, and a view that will be a dim one for those coming along behind us

There is another point worth considering Aware that the world is using up energy at such a rapidly increasing rate, we sometimes forget that 30 per cent of the people are using 85 per cent of that energy In other words, there are many more 'have nots' with respect to power than there are 'haves The goal of society is to bring all its peoples up to the highest level not drag them down to the lowest If such a goal were to be realized in the next fifty years with each of the inhabitants using energy at the rate the power-rich now do, our reserves of fossil fuels would probably be gone forever!

There seem to be two possibilities on the horizon One of these is the harnessing of nuclear fusion—duplicating the solar process right here on earth To do this we must deal with temperatures of millions of degrees and forces that so



Association for Applied Solar Energy

John Yellott left and youthful assistant use sun s heat to cut ribbon at formal opening of AFASE solar house

ton D C At least one solar-heated office building has been built as well Hot water and air are both used as the heat transfer medium and storage schemes range from bins of gravel to water tanks and even chemicals that store great quantities of heat

Perhaps the most elaborate solar heated house was that

constructed near Phoenix, Arizona, by the Association for Applied Solar Energy In this home winner of an international architectural competition the heat collectors were parabolic trough louvers automatically turned during the day to follow the sun The swimming pool acted as a storage tank for heat

A solar home-heating plant is costly, and few buyers care to 'risk the extra outlay for a solar plant over a conventional gas or electric heating system However, the Thomason houses incorporate a modestly priced solar air-conditioning system which its inventor thinks will repay the difference in several years

In the Thomason house part of the roof acts as a heat collector through which 1,600 gallons of water are circulated Heat thus transferred to the water is stored in a tank in the basement, surrounded additionally by rock heat storage Ingeniously designed despite its simplicity and low price, this system heats the house in winter heats water the year round, and even helps cool the house in summer To do the latter, water is circulated from the storage tank to the roof where it cools by evaporation during the night This water is drawn on during the day to cool the house

Because of the possibility of a long period of time with insufficient sunshine to heat the storage tank, the house is equipped with a standby oil fired furnace Seemingly an admission of defeat this is a more or less standard design philosophy that has evolved for solar space heating While it is *possible* to provide all the heat necessary with solar collectors it is not economical to do so as we move farther north In sunny climates at low latitudes a small collector and storage system will provide all the necessary heat To do this in New England or Canada would require a huge collector and a huge storage area There is thus a point of diminishing returns and engineers find it wise to plan for

only a percentage of the total heat needs with solar energy To carry over through long cloudy periods or continued very low temperatures, supplementary conventional fuels are provided

Washington is just at the edge of the solar belt ' almost at the 40th parallel of latitude, and would thus seem a marginal location for the use of solar heating However, Thomason reports using only $4 65 worth of supplementary fuel for an entire season! To make the system even more efficient he also heats a swimming pool with solar energy Some further bonuses are an emergency water supply for drinking in case of disaster or for fire-fighting!

The sun can refrigerate a home as well as heat it and many experts think that cooling actually offers a greater potential for solar energy since the supply is at its peak when it is needed most This is just the reverse of the situation when sunshine is used for heat Solar refrigerated homes have been built and the feasibility of the system has been demonstrated, the economics remain a stumbling block It is still far cheaper to air condition a house with electricity or gas For example one experimental cooling system included a copper roof which cost several thousand dollars! The answer lies in paring costs to make solar energy methods competitive The field is new and great advances have been made A breakthrough in materials or perfection of existing designs coupled with wide demand could make solar air conditioning practical in a few years

Again situations dictate developments Just as solar panels at a quarter of a million dollars may be a bargain for a kilowatt of power a thousand miles out in space a solar refrigerated and lighted home a thousand miles from the end of the nearest railroad or highway might also be a bargain While a g llon of oil may give us 100 000 Btu s for just a quarter if it costs us a dollar to haul in that gallon the econ

omy takes a decided plunge and solar power at a capital cost that looks at first glance like a hopeless extravagance seems a better buy

Water Heating

At least two homes have included swimming pools in the solar heating system, but hundreds of pools are being heated separately by homemade solar collectors or one of several commercial models on the market While a large collector area is needed and sometimes poses architectural problems the attractiveness of the scheme [illegible] obvious when it is remembered that a gas heater may d[illegible] several hundred dollars and require forty dollars a month to operate

While solar energy does n[illegible] yet heat a great number of homes, or even swimming pools domestic solar water heaters abound Florida has an estimated 25,000 units in operation, heating water for private residences apartment buildings and even laundries This success depends on several factors First is the large amount of sunshine available Improved designs competitive costs of operation and aggressive manufacturing and sales organizations add to the natural blessing of the state to put the sun in business

The solar water heater has been with us for many years and in some southern states aging pioneer installations can still be seen in operation California in particular took to the solar heater and its rooftop glass-covered heating coil But technical progress and financial affluence outmoded these early power savers and they have only recently begun to appear again In present installations standby electric or gas fuel is called on when the tank temperature drops too low In the meantime, appreciable fuel savings are realized

Mountain cabins and remote camp sites would seem

logical customers for solar water heaters perhaps portable units may soon be available for campers Already campers are using another solar energy device to heat not just water but food as well

Solar Cooking

There are several types of reflector cookers on the market Perhaps the most popular is the Umbroiler an umbrella like reflector equipped with a grill Easily packed in a box for transporting it can be set up in a minute or so and in about fifteen minutes in bright sunlight can boil a quart of water or broil hot dogs or hamburgers

Although as yet campers have not deluged the manufacturer with orders the solar cooker is a practical piece of outdoor gear It will broil steaks or cook bacon and eggs before a bed of charcoal can be burning well For trips, there is no need to take along fuel of any kind which is a saving of money and space No matches are needed and there is no bothersome smoke Also attractive is the fact that the solar stove is far safer with respect to forest fires than are other means of cooking

Akin to the reflector stove is the solar oven Also portable this unit is light in weight and delivers temperatures as high as 450 degrees Equipped with folding reflectors to increase the amount of heat trapped the oven works on the green house principle Heat goes in through the glass top but is not reflected back out More compact and easy to handle than the reflector stove the oven need not be as accurately pointed toward the sun Some ovens have been equipped with special containers of heat storing chemicals and can cook for several hours after sundown The obvious disadvantage of solar cookers or ovens is their dependence on the sun At night in the shade or during a rain they are of little

use, though camp stoves are generally intended to be used during daylight and in good weather

Besides its applications for cooking food and heating water, solar energy can refrigerate food and make ice as well In fact the trend of thinking now seems to be turning



Scouts sampling solar cooked hamburgers in Arizona

strongly in this direction There are some good psychological reasons for this paradox In India Mexico and South America where solar cookers have been tried, there is resistance to them simply because it is still possible though perhaps difficult to round up firewood, animal dung or some sort of fuel for cooking Ice on the other hand cannot be obtained in such a primitive manner Thus many think that

the native who does not seem much interested in the solar stove would look more favorably upon a cheap refrigerator run by the sun in which he could keep milk and other perishables Experimental work has been done with simple absorption cycle refrigerators regenerated daily by solar energy for two hours or so Here too the disadvantage of darkness does not apply since the refrigerator will stay cool during the night

Water Distillation

As we run out of space we also seem to be running out of fresh water for drinking and irrigation Already the distillation of sea water has been resorted to in many locations in the world, and here again is a broad area of possibility for solar energy Distilling water requires heat, the most easily obtainable form of solar energy When water evaporates the impurities are not taken up in the vapor Thus when the vapor condenses on an appropriate surface it is pure and suitable for drinking irrigation industrial uses and so on

The solar still has been mentioned in the small emergency type as used by downed airmen Large-scale stills too are not new and back in 1872 a Chilean solar still delivered 6 000 gallons of fresh water a day Built of wood and glass it served for many years with little maintenance and permitted economic operation of a mine in an area with no other fresh water available With improved materials like plastics available more efficient and more economical stills are possible today and much work is being done in this direction

The Office of Saline Water, Department of the Interior, has for some years sponsored research in solar stills along with its other research in the field of distillation Battelle Memorial Institute is among those active in this work with a research station at Ponce de Leon Lighthouse Reservation

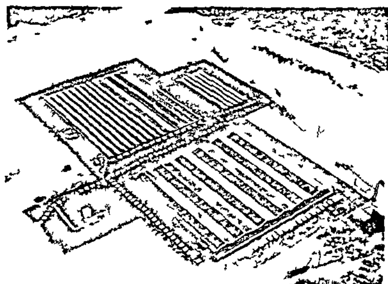
near Daytona Beach Florida Franklin Institute Georgia Institute of Technology, New York University, Bjorksten Research Laboratories Inc, Dr George Lof, and New Mexico Highlands University are also doing research for OSW Massachusetts Institute of Technology and the University of California maintain research programs, and are also working on solar stills of various designs The main problem is to get the cost of distillation per gallon down to a competitive price

Cheap fuel is the solar still s competition Conventional distillation plants produce fresh water for thirty cents per thousand gallons, and solar plants are nowhere near this figure However the Office of Saline Water feels that progress is being made in its tests with deep basin," ' tilted wick," and forced convection types Initial costs are high, particularly when construction is of concrete and glass for long life Saving money with plastic covers instead of glass has been accomplished, but hurricane Donna wrecked a promising air-supported plastic still in 1960 It is of interest that the still withstood the gale until power for the air pumps failed, however, and that far heavier structures were also wrecked by the storm

Reporting at the Rome Energy Conference in 1961, J J Strobel of the Department of the Interior gave estimates for a 100,000 gallon a-day solar still based on work with pilot plants Such a still could cost one million dollars and deliver fresh water at a cost of $1 22 per thousand gallons, several times that of conventional distillation methods

The solar still is not attractive from an economical standpoint today for several reasons First, initial costs are high, though this disadvantage is offset by long life and low maintenance Second the still requires a very large area compared with conventional stills Finally, the price per gallon is still high by a factor of about four

It is nice to know that the solar still will work however, and that we can provide ourselves with fresh water in the future when conventional fuels are gone Even paying a premium will not be much penalty since water is one of our cheapest needs Solar scientists are constantly seeking im



Battelle Memorial Institute

Solar fresh water still research station operated by Battelle Memorial Institute for Department of Interior Deep basin still in the foreground with plastic air inflated stills beyond

proved methods Recently a student at the University of Arizona designed what seems to be a much better still and one which might drop the price to a figure close to that of conventional plants

Solar Electricity

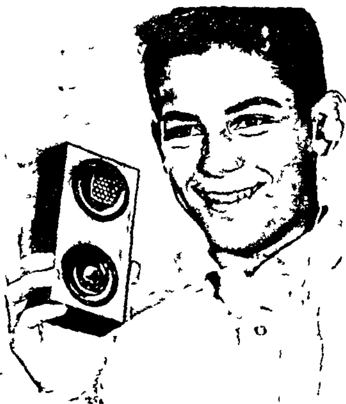
Moving from the use of solar heat we come to applications involving solar generated electricity Oddly, most of

us are more familiar with what solar batteries are doing in space than with their accomplishments here on earth While the total kilowatt-hours produced by such terrestrial appli cations do not add up to enough to worry utility companies greatly, there are quite a few devices now drawing token electric power from the sun

Solar powered radios in a variety of shapes and sizes have been mentioned from tiny transistor models using one solar battery to long-range communication equipment powered by large panels Solar batteries are being used in Africa and South America, and experiments with ' listening stations in remote areas show promise Solar-powered emergency signaling stations along highways and freeways have been tested and it is pointed out that since such units are self-contained and require no power lines and little maintenance, they are economically attractive even now

International Rectifier Corporation, a supplier of solar batteries for the space effort, has developed a broad line of educational kits featuring solar batteries Such efforts stem from two reasons Production of high efficiency solar batteries for space satellites delivers a byproduct in the form of lower efficiency batteries In other words, a thousand mass-produced solar batteries may range in efficiency from 5 per cent to 14 per cent The space effort demands only the top bracket of 12 per cent to 14 per cent Other applications take lower efficiency say 10 per cent to 12 per cent Those lower than 10 per cent must be disposed of elsewhere if they are not to reflect a total loss and consequent increase of the top-grade cell price Educational and hobby kits, commercial radios and so on, are the answer At the same time such advertising is hopefully building a broader market for the solar battery against the day when economical medium-efficiency types may be used to power an outboard motor or even a complete house For the moment however the solar battery would seem to be of prime importance to the science

of electronics of which it is such a recent offspring In addition to radios phonographs have been run on sunlight, as have clocks, electric shavers, sewing machines flashlights and beacons in lighthouses and airways markers



International Rectifier Corp

Youngster listens to transistor radio powered by solar battery in top circle

The use of sun power for transportation has been an idea reserved for the science fiction writer and the suspect scientist. Toys have been powered with solar cells of course Trains, boats and autos, are among these The propellers of

model airplanes have also been made to whirl realistically, though not to pull the craft through the air But any suggestion that sun power could actually drive a man-carrying vehicle has been met with loud snorts of derision even from the solar scientists themselves When a sporting goods firm displayed an artist's conception of a solar-powered outboard motorboat even solar energy experts advised against buying stock in any such idea And the notion of automobiles driven by sun power was likewise flayed Yet within a few years both these impossibilities have come to be

The Solar King' panel built by International Rectifier Corporation was used to drive their Baker electric car Mounted on the roof of the antique 1912 auto, this large solar panel charged the storage batteries in the car and after sufficient exposure to sunlight the car could be driven for several miles, actually on sun power! Of course the idea was a demonstration, and there has been no rash of solar-powered electrics blocking traffic on the freeways

The solar powered boat built by the Agency for International Development for use in South America while not as racy looking as the outboard mentioned above, actually is powered by the sun, and the fact that it ended in a controversy detracts nothing from the concept An educated guess as to the future of transportation is that it will be electrically powered—with electricity quite possibly generated by solar energy though not necessarily on the roof of the car itself Perhaps the car will be plugged into a wall socket in the garage to charge up from a large collector on the housetop

The Solar Furnace

There is an even simpler use of solar energy in the form of heat Instead of changing it into electricity or steam or

whatever, the heat at the focal point is used as *heat* An example is the solar furnace, one of the most spectacular applications of solar energy A favorite trick of public relations people—though it must depress the scientist—is that of shoving a two by-four into the hot spot' where it takes flame almost instantly With a big enough furnace a steel beam



International Rectifier Corp

Dr Charles Escoffery developer of this solar powered Baker Electric car chats with skeptical Central Park policeman Four by five foot solar battery panel on roof charges storage batteries for car s operation

can be substituted for wood These attention getting feats are analogous to using a telescope to look into bedroom windows but perhaps they are worth the scientists anguish

Archimedes used the concentration principle to produce fire at a distance the scientific or industrial solar furnace is focused closer at hand and is thus a more controllable tool After World War II with the upsurge in high temperature research for fast flying aircraft and missiles scientists turned to the solar furnace to produce the elevated temperatures

needed There were plenty of them available, in the form of surplus searchlights The searchlight mirror is designed to reflect the light boiling out in all directions from the carbon arc in a tidy parallel beam The parabolic shape of the mirror has this property, and of course it works both ways The parallel rays of the sun striking the mirror are reflected to the focal point of the mirror The better the mirror the smaller the spot and the greater the temperature

Even the aging searchlights did a commendable job and many aircraft firms and others in the field mounted makeshift furnaces on the roof and worked out tracking rigs to follow the sun The bright spot of light at the focal point might be several thousand degrees Fahrenheit, and all manner of materials were melted or oxidized, or burned, unless they survived the temperature A few furnaces, some as large as ten feet in diameter, were specially made for the purpose, but for a really large solar furnace it was necessary to look to France

At the end of World War II, scientist Dr Felix Trombe interested the French government in building a solar furnace for research There was an old fort at Mont Louis in the Pyrenees, high enough for the air to be clear and loaded with sunshine It was, Trombe felt, an ideal spot for solar research The government agreed and with amazingly modest funds Trombe and his fellows built what remains today as the largest solar furnace in the world

Spanning thirty-five feet, the huge vertical parabolic collector is composed of thousands of plane mirrors accurately curved with tiny adjusting screws and all focused at one point Some distance away a large flat mirror called a heliostat is mounted so that it can move horizontally and vertically to follow the sun Thus during daylight hours the sun is reflected by the heliostat onto the parabolic mirror and thence to the focal point

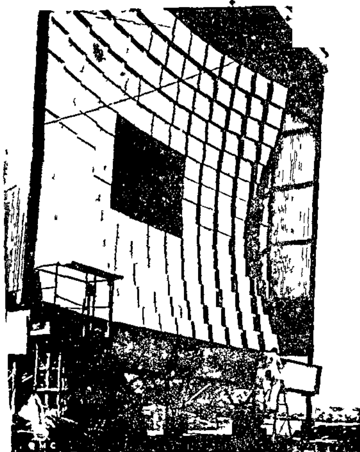
Developing seventy five kilowatts the furnace is not used

both for research and limited industrial use The French furnace used for research and production is an example At Stanford Research Institute American scientists are using a solar furnace to investigate the as yet unexploited photochemistry field and have shown promising though low-efficiency conversion by means analogous to plant conversion of light into energy

A modest sized furnace can be built by a hobbyist, and these have been used for tasks ranging from the firing of ceramics to the brazing soldering, and welding of high-temperature metals Do-it yourself furnaces deliver temperatures of about 2 000 degrees Fahrenheit sufficient for a number of applications, including the burning of fingers Even with these small furnaces it has been found wise to wear dark glasses to protect against the white hot glare of the focal point

In the laboratory the solar furnace finds use as a measurement tool for temperature, emissivity melting point, thermoelectricity thermionic emission evaporation rates, and radiation standards It is also suited for such tasks as the growing of single-crystal material in which purity is of prime importance zone refining, and so on Interestingly, you will remember that the solar battery itself is a product of single-crystal technology Perhaps the solar furnace can produce higher purity material for fabrication of better batteries Another use of the solar furnace is for high temperature welding in an inert atmosphere Welding of thermocouple beads cutting and joining of ceramic materials and so on are examples of this technique

A suggested use of the solar furnace in space exploration is to obtain water that may be found entrapped in the rocks on the moon It may be used in such lunar explorers as Surveyor which will land on the moon and make spectrographic analyses of materials



US Army

Largest solar furnace in the United States the concentrator of the U S Army Quartermaster Corps high temperature furnace The 180 concave mirrors produce 5 000 degree temperatures sufficient to melt steel I beams

Like any other solar device the solar furnace has inherent disadvantages At night it is of no use although scientists have used moonlight to perform certain tests on the furnace mirror Understandably the solar furnace is limited to

the hours of sunlight and it must have clear air to generate truly high temperatures Areas where the air is smoggy or otherwise polluted are not good locations for solar furnaces

Rain or other precipitation, haze, fog, and clouds are also undesirable Even wind can detract from the effectiveness of the furnace, since orientation is a critical factor and high wind loadings may cause sufficient deflection to spoil the accurate focus of the sun s rays into the desired small spot Further mirror surfaces must be kept clean to prevent losses of efficiency This presupposes a protective cover, and we find that the solar furnace has become something like the astronomical telescope, good for only part of the twenty four hours, best at high altitudes and requiring an expensive housing to protect it from the elements

These disadvantages can of course be overcome and General Electric s desert facility near Phoenix with sliding roof is an example Perhaps the hundred foot furnace will never get farther than the drawing board but this does not mean that two or three fifty footers won t be built and do an excellent job both for research and for industry

Power

Use of our rooftop to gather heat for warming or cooling our home is a not too-far fetched idea to most of us A trip to the attic in summer is proof of the amount of heat that finds its way even through a roofing material designed to keep it out But the use of the roof as a power plant for generation of electricity for domestic lighting cooking communication entertainment and miscellaneous power needs for mowing workshop and so on is a more challenging idea

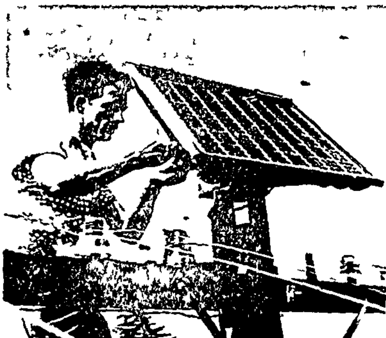
The heat falling on our home is sufficient to warm it in winter and cool it in summer Beyond that it is enough to

provide all the other energy needs of the house, as described above, with a good margin of safety—if we can learn ways of availing ourselves of it Back in the early days of the solar battery, the solar shingled roof was an eye catching idea A roof 20 feet by 40 feet converting solar energy to elec tricity at 10 per cent efficiency, would provide sufficient kilowatt hours to service a home on only 5 days of sunshine a month! The obvious fly in the ointment then, as now, was the price of the solar shingles At current prices such a roof would cost hundreds of thousands of dollars and would take many lifetimes to pay off even with no maintenance costs or replacement

For a time the solar roof was the butt of ridicule, and its proponents were accused of overselling solar energy More recently, however the idea has moved from advertising brochure to scientific journal, and learned treatises have been written by scientists and engineers proposing these rooftop power plants One writer even suggested tying in the home power plant with the public utility Then, when the roof was receiving an excess of power this surplus would be carried off by wires for use elsewhere The watt-hour meter would in effect run backward at these times to lower the householder s bill Appealing as this arrangement might be to those of us paying the electric bills it has been deemed uneconomical by other experts in the power field Why suffer the losses in the transmission lines they argue Why not build storage facilities into each house and have a self contained power plant on each roof? No longer would we need unsightly poles and wires that are also a hazard and an expense And electrical power would be no more costly in rural or even remote areas than in town

Despite the increased optimism of scientists the cost factor is still against the solar shingled roof although some progress is being made International Rectifier Corporation s

"Solar King" is 4 by 5 feet, giving 20 square feet of area This panel was built for about $15,000, and our 800-square-foot roof would still cost $600,000! However, the firm feels that it could produce such panels in quantity for as little as



Bell Telephone Laboratories

First commercial use of solar batteries on Bell Telephone System at Americus Georgia Tests proved the feasibility of the idea but it is not yet competitive with conventional power

$2 000 thus dropping the roof price to $80 000 Even at this bargain figure, of course, not many of us are going to swing to solar power just yet A 20 foot panel for $2,000 *gives us solar power for about $100 a square foot* Experts are talking of $1 to $10 a square foot as a realistic price that will make the solar rooftop power plant an actuality

Generally the industry is hopeful, and serious scientists talk of solar "mats" four by eight *feet* suitable for roofing material and wired together in series-parallel combinations to provide suitable voltage for power supplies

A rooftop plant could take care of our home power, but there will always be a need for larger central power generation Many fanciful drawings have appeared showing huge solar installations producing megawatts of power and taking care of sizable towns These are dreams as yet, and despite talk by Soviet scientists about a large solar-powered steam plant being built in Tashkent, it is only recently that the Russians have been able to produce a practical solar engine of even modest size

Even the optimists among solar workers feel that in the United States solar electricity on an industrial or utility basis is decades away, although its use in remote areas may well be economical long before that It also seems that, barring a sudden breakthrough in solar battery technology, the solar mechanical power plant will be first in practical operation in the underdeveloped areas of the world

The National Physical Laboratory of Israel is a hotbed of solar energy development There is good reason, since it is located in a land of plenty as far as sunshine is concerned and a land of not so-plenty otherwise The Tabor turbine operating on solar energy in Israel is an excellent example of this type of solar converter and today is attractive from a financial basis not just as an amazing oddity of science Even assuming a life of some 5,000 hours for the solar turbine, the Israeli workers show a cost for electric power of only about 3½ cents a kilowatt hour, 10 000 hours of operation would drop this to 1¾ cents

A small steam turbine cannot operate more efficiently than about 5 per cent so Tabor substituted a different working medium He uses monochlorobenzene, whose high

molecular weight permits the specially designed turbine to deliver an efficiency of between 15 per cent and 20 per cent at an operating temperature of about 150° C. The turbine runs at 18 000 rpm and drives a 50-cycle alternator

Since rigid metal collectors that follow the sun are expensive the Tabor plant is equipped with a stationary plastic collector this is a long transparent tube coated with aluminum on half its circumference and inflated under low pressure Three of these plastic collectors provide heat for the turbine and they require tilting to follow the sun only once a week Despite the delicate appearance of the plastic, air inflated tubes they can withstand gales of sixty miles an hour and are expected to last a minimum of six years

Another bet for the low power solar engine field for terrestrial use is the Stirling hot air engine the first of which may well operate in space hundreds of miles from earth Because of the simplicity and efficiency of the improved engine developed at the Battelle Institute workers there and elsewhere feel it will make its mark in terrestrial applications along with Dr Tabor s turbine

Also being developed for small scale power plants are thermoelectric and thermionic converters currently figuring in space applications Radio Corporation of America engineers have designed and tested thermoelectric converters using metal reflectors to concentrate sunlight and produce small amounts of power for use in rural areas Such power plants can pump water and provide electricity for lighting and communication refrigeration and other uses

Hamilton Standard Division of United Aircraft has taken a more expensive but simpler tack and built a hundred watt power supply for the United States Army Signal Corps using solar batteries Compact, light and foldable for portability, such a power pack might also be of use for engineers, explorers and others in remote areas Westinghouse is

developing such thermoelectric converters and General Electric considers that its thermionic converters for use in space could also generate economical power for terrestrial uses

France, with the world s largest solar furnace, also lays claim to the largest thermoelectric generator Built near Toulon jointly by the Society for the Study of Industrial Applications of Solar Energy and the African Investment Bureau, a 170 foot prototype has been studied to pave the way for a 700 square-foot generator now under construction This is about the size we need for our rooftop power plant, incidentally

Initial cost is the obstacle with solar energy installations In the case of the Tabor solar turbine and similar plants, the turbine or engine is comparable in operation and cost to one using conventional fuel The fuel is replaced by the solar energy collector, and thus the economy of solar power hinges on the cost of the collector In the case of the Tabor solar turbine, the plastic collector represents some 75 per cent of the total initial cost The cheaper the collector, the closer we approach free power from sunshine Some of the most interesting solar energy applications take this approach the idea of cutting collector cost drastically

Many years ago some engineers were aware of this economic fact of solar energy and proposed simple collectors consisting of shallow ponds of water glassed over The idea was good but not good enough It has taken time for better concepts and better materials to make such ideas practical One of the better ideas is that of the Israeli scientists in adding chemicals to solar ponds to increase heat absorption of the water progressively from surface to bottom, prevent ing normal convection of heat and storing it more effectively A better material than glass is plastic which is cheaper lighter, more easily handled and more transparent

to light As a result, a large solar pond properly designed and constructed ill trap a high percentage of the energy the sun showers on it and this energy in the form of stored heat may be drawn on to furnish electric power on a twenty-four-hour basis Ponds are being tested in the biblical city of Sodom

A similar idea but one which may offer far greater potential is the sea thermal energy plant, called STE for short STE works because of the temperature difference between the water near the surface and that near the bottom which in some cases is as great as 40° F The idea is not new having been tried by the French scientist Claude many years ago But again it has had to wait for better techniques and better materials

The sea represents perhaps the cheapest collector of solar energy available and since the sea covers three-fourths of the earth s surface it receives most of the solar energy reach ing us In coastal areas in semitropical regions the idea of sea thermal energy is appealing and much research has been done toward such installations The Clearing Division of United States Industries Inc has worked out detailed designs for an 8 000-kilowatt plant to cost between $2 5 and $3 million This is about $350 per kilowatt and competitive with a conventional plant in such an area In addition to electric power the sea thermal energy plant produces fresh water and could also recover salt and other valuable minerals in the process

We are familiar with the heat pump which operates in a manner similar to the sea thermal energy plant or solar pond Although not generally appreciated as such the heat pump is truly a solar energy device since it draws on solar heat stored in water air or earth While conventional electric heat pumps require about one equivalent unit of commercial power for each three units of heat they reclaim from the

working medium, they are highly desirable from the standpoint of conserving our natural fuels The possibility of furnishing the required operating power with a solar engine has been proposed, and may represent as efficient reclamation of solar energy as is possible

Summary

Already the sun has demonstrated that it can heat our homes and cool them It can cook food and heat water, distilling the water first if need be Solar heat is available at high temperatures and at a purity unmatched by other sources Solar electricity is here although not yet at a penny a kilowatt hour

Beyond these methods of recovering solar energy are the more exotic proposals of 'energy farms in which plastic films covering acres convert sunlight into electricity, and the extraction of fuels like hydrogen, nitrogen and ammonia from the atmosphere by using solar energy

There is another terrestrial use of solar energy we have mentioned only briefly so far but it is one with tremendous implications Food is as big a problem as water, perhaps a bigger one Research in the production of algae suggests a means of supplementing scanty supplies of conventionally grown foods This is photochemistry one of the most intriguing phenomena we have encountered Plants have been using solar energy since the beginning of time and now man is prying into this mystery in an effort to use the sun better Photochemistry is such a broad and interesting subject that we will devote the next chapter to it

8

Photochemistry Light Magic

All of the stored up fuels man has inherited on earth the coal and oil that nature has stockpiled slowly through eons of time are products of a single phenomenon that of photosynthesis Logically then it would seem that as man began to convert solar energy into power he would look to nature in an effort to copy this method that produced all his fossil fuels and also the food that keeps him alive

Strangely man has done least in harnessing sun power with the method used so successfully by nature We have talked of electrical or mechanical conversion and pointed out that these have been developed to a fair degree of efficiency These are physical methods that find no counterpart in nature surely not in the phenomenon we will concern ourselves with in this chapter that of photochemistry

A definition of photochemistry is simple and derives directly from the two words making it up It is the study of

chemical reactions produced by light, including the near ultraviolet, the visible, and the near infrared There are two common photochemical reactions man profits from photo synthesis and photography In photography man has done something nature does not do, in photosynthesis the opposite is the case Since nature is the real thing, the model for the photograph there is indeed little reason for her to indulge in anything as secondhand as photography Man, however, would dearly love to duplicate the process of photosynthesis and does not only because thus far he cannot

While the definition of photochemistry is simple, the process itself defies man s detective work to analyze it It is a highly complex happening which man can describe, in terms including photons Planck s constant, and even "ein steins of light but which he cannot explain

Plant life is literally a living example of the conversion of solar energy to a usable chemical energy A wheat field soaks up the sunshine bathing it and changes the light into calories of heat energy in the plant This energy is stored for months or even years, in huge silos is finally made into flour, baked into bread, and eaten by us humans to provide the heat energy to power our bodies for their various tasks With the apathy accorded the commonplace we look with little wonder and scant respect on the growing plant forget ting that it is sophisticated beyond our scientific comprehen sion The conversion of sunlight into electricity in a solar battery is much more exciting to most of us

The great part that photosynthesis plays in life on earth comes into better focus when we consider the magnitude of the work plants do each year It is no mean feat, combining 150 billion tons of carbon and 25 billion tons of hydrogen into energy-rich hydrocarbons, and producing 400 billion tons of oxygen in the process! And if these clever and busy green plants were to disappear so too would life as we

know it Man needs heat energy to live and is constantly bathed in such energy from the sun But he cannot convert sunlight into food himself Man in space could not exist without stored up food he can on earth simply because his plants work for him to turn sunlight into a source of energy compatible with his body structure

Many authorities, including Dr Farrington Daniels feel that photochemistry, of which the photosynthesis of plants is nature s prime example, is the ultimate hope of man in putting the thus far wasted energy of the sun to practical use

Photography, an aspect of photochemistry that man has more or less mastered has a long history of study but not as long as that of photosynthesis Even primitive man was aware that the sun made his crops grow, although for thou sands of years he was content merely to accept that fact and make an occasional sacrifice to the sun god As scientific questioning supplanted cult and magic, men began to study the relationship of sunlight and plants During the seventeenth century, a Flemish chemist named Van Helmont conducted the first scientific studies of plant growth and made the astonishing discovery that the needed material did not come from the ground as had been thought Instead, it must come directly from the air and from the sun In 1727 a paper titled Vegetable Staticks ' was published by Stephen Hales it was the first of the formal literature on photochemistry

During the eighteenth century Hales's work was continued by Priestley Ingen Housz Senebier and de Daussure In 1845 von Mayer was able to state clearly that sunlight provided the energy that effected plant growth and the equally important consideration that this sunlight was ultimately recoverable from nature s photosynthetic products This concept hinged on the tossing out of the false ' caloric

theory of heat and the establishment of the principle of the conservation of energy With the photosynthesis concept firmly laid down, scientists started to work in the field of quantitative photochemistry

In our century scientists have begun to pin down the "quantum" efficiency of photochemistry and to dig into the riddle of how chlorophyll changes light into chemical energy But even with nearly two hundred and fifty years of investigation, and a large body of formal literature, there is little known today of how the plant achieves this deceptively simple transformation of energy from light to chemical storage

Essentially, photosynthesis consists of the reduction of carbon dioxide to form a sugar, and the splitting of water to produce oxygen One writer likens the process to a hand-cranked mill, into the top of which is dumped water and carbon dioxide The crank is turned its energy being analogous to that of sunshine and out the bottom come sugar and oxygen This marvelous machine unfortunately is something like the goose that lays the golden eggs, for when we cut into it to see how the trick is done we ruin the wonderful mechanism and learn nothing for our pains Thus the scientist has had to treat photosynthesis largely like the black box' of his electronic brethren in which only input and output are known

We can of course rationalize this lack of progress in duplicating artificially the photosynthesis of nature Although the growth of a plant is miraculous it is also very low in efficiency Corn is about the most efficient converter of sunshine but it does this at a rate of about 0 3 per cent Only because of the sun s effectiveness in producing energy is there nearly enough food for all the billions of us on earth Some plants like wheat are less than half as efficient as corn and the average is perhaps between 0 1 per

cent and 0 2 per cent So, for all the magic of chlorophyll man might well wonder if the secret is worthwhile with a return of such low magnitude The solar battery remember, converts as much as 14 per cent *of the total solar energy* a whopping percentage when compared with corn s tiny $^{3}/_{10}$ of 1 per cent Such rationalizing is of course unscientific and shortsighted and so biologists chemists, and more recently solar scientists are eagerly studying photosynthesis

Photosynthesis

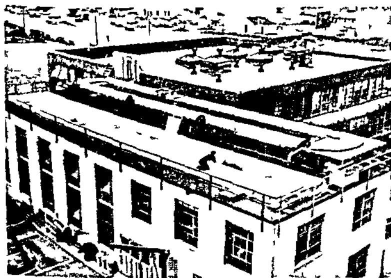
The fanciful tale of Jack and the beanstalk has an appeal not just for youngsters but also for those concerned about *feeding the hungry population of a rapidly growing world* The idea of dropping a seed into the soil and jumping back to avoid being lifted heavenward would seem to have little chance of ever being more than just a dream but there are some interesting developments to ponder

Normal crop production is unlike Jack s magical beans and is about three tons per acre per year Despite tales of plants flourishing to music or well intended prayers, the main thing that makes them grow is sunlight combined of course with water and carbon dioxide This is indicated in laboratory experiments producing freak plants that shoot up at a great rate because they are being force fed But almost beyond belief is the fact that, theoretically it would be possible to grow three tons of crops per acre in a singl *day!*

Such a yield would make Jack s beanstalk seem a lazy pot plant and throw our Agriculture Department subsidy ex perts into a tizzy *Of course no such bumper crop as this is in sight* but when we recall that plants convert only about a thousandth of the energy available and that an acre normally produces about three tons annually the figure does not seem

so unreasonable In fact, scientists have already begun work in the direction of producing more food per acre by giving nature a helping hand The object of this photochemistry research is the alga *chlorella pyrenoidosa*

In 1951 the Carnegie Institution of Washington engaged the firm of Arthur D Little, Inc to demonstrate the pro-



A D Little Inc

Rooftop installation of first large scale algae culture program Sun light trapped in oval plastic tanks causes rapid growth of the micro-organisms

duction of algae on a commercial scale Work had earlier been done with laboratory growth of these microscopic or ganisms, but this was the first attempt at building what was in effect a pilot plant

Algae are more familiar to most of us as seaweed, or as the green scum growing on ponds Their use as food is not particularly appealing, at first glance, but then the tomato was considered to be poisonous for many years before it was

first tried and accepted as a food The plant that Arthur D Little built in Boston was a spotless installation and produced its algae not in open air on a scummy pond but in the clinical sterility of closed tanks

A large plastic tank, laid out in an oval covered six hundred square feet In it 1 200 gallons of water were circulated by a centrifugal pump and cooled by heat exchangers since the algae refused to grow above certain temperatures As the microorganisms circled their big racetrack air containing 5 per cent carbon dioxide was fed into the plastic tube Thus sunlight was gotten to the algae more efficiently and far more carbon dioxide than nature s provision of 03 per cent was available

The plant operated for about three months and in that time produced some 75 pounds of dry algae For 1 acre this converts to 20 tons per year compared with about 3 for dry land farming of the conventional type Man despite his inability to understand how photosynthesis takes place was able to better nature appreciably in the first quantitative test of algae culture Based on pilot plant work a 100-acre plant was next studied on paper A yield of 35 tons per acre was estimated because of improvements to be made and output for the plant would be more than 6 tons a day at a cost of about 25 cents per pound

Japan has done extensive work with algae culture, both in closed circulation tanks and in shallow open tanks The latter system has the advantage of low cost and the disadvantages of contamination and evaporation The Japanese estimate of the cost of producing a pound of dry algae was amazingly close to those of the Little researchers and was given as 25 8 cents This put the algae protein price at about twice that of soybeans half that of egg and one fifth that of milk

The Japanese have gone further with actual human con

sumption of algae, and compare them with other powdered products like green tea and seaweed Since they have a strong aroma and taste of fish, algae are best mixed with something that goes well with that flavor Noodles and rice crackers are suggestions though the dark-green color of the algae darkens the food quite a bit and may not be acceptable The powder has been successfully added to candy, cake and soft drinks

A soybean soup called *miso* is a staple breakfast item with the Japanese and algae have been mixed about one part in eight with this soup Ice creams and fish flakes were also tried Algae seem to have about the nutritive value of yeast, but even less taste appeal The Russians, in fact, object to them as a food for human beings except indirectly as when they are fed to animals raised for meat

More recent work with algae does not seem to have lowered prices, and some researchers feel that fifty cents a pound is a more reasonable estimate of product cost in the marketplace They state that this price will not be economically justified until it can be shown that there is special nutritive or other value to make algae more than a simple food substitute Interestingly, algae are now being grown with deuterium, or heavy water, waste from atomic plants substituted for hydrogen The resulting solids may well be of the special value to make the algae phase of photosynthetic research pay off

Proponents of algae culture still claim they are on the right track pointing out that there is room for much improvement in the annual yield—perhaps to a figure as high as 100 to 110 tons—and also that methods may be made more economical as for example, by using strains of thermophilic, or heat-tolerant, algae so that cooling of the water will not be necessary Beyond this is the undeniable truth that artificial photosynthesis' like the algae culture that has been

achieved is quite possible on land otherwise unusable for agriculture It is also quite likely that when we run out of food we will be more than willing to pay a premium for methods that will produce ten times the normal yield

The idea of using photosynthesis to produce power—in effect short term fossil fuels'—is intriguing, even though it seems doomed by arithmetic Food may of course be con sidered a fuel, since it provides the motive power for our bodies Gasoline produces calories in the internal combus tion engine it is intended for, a stack of hotcakes does the same thing for the human machine The calories we heavy-weights count so worriedly are essentially the same as those that drive a steam engine, they are heat energy There is a big difference however in nature s production of the hydrocarbon fuels we use and the food we eat Sufficient food is grown currently and continuously the bulk of our fuels have been produced over millions of years and only those like wood are of the income' variety

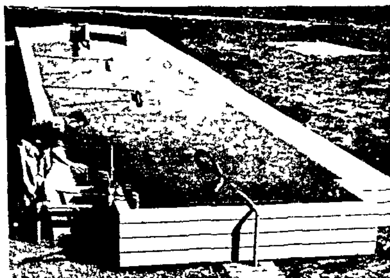
There are ways of converting woody products to liquid or gas fuels for example, the Fischer-Tropsch process This might take the thirty five tons of algae grown on an acre and reduce it to from six to nine tons of fuel Trying to adopt a simpler farming concept, it has been suggested that we simply grow more wood as fuel Unfortunately this pleasant solution is more naive than it sounds, a forest of the fastest growing trees known and covering the entire world would not do the trick! Suggesters of the idea apparently couldn t see the woods for the trees Even the more efficient algae culture method of converting sunlight to fuel would not work If we burned all our crops to produce fuel as has been done on a small scale during wars we would still be short to say nothing of hungry

Quite recently however there has been a new develop ment which may change the outlook for algae culture dras-

tically Scientists have produced what they call bio power or electricity from living cells and such an application may lift photosynthesis into a possibility as a power source

The ' Bug Battery"

We are used to the notion of living things turning sun light into matter and accept this phenomenon on faith



Uni ersity of Ari-ona

Open tank culture of algae a simpler method than the plastic tank

though we don t know quite how it comes about Nature s creatures also convert sunlight to electricity generally in an indirect enough way for us to miss the significance Galvani and his frogs proved the existence of electric current in living things and the electric eel does not shock many of us in the figurative sense Most of us know that our own brains operate on feeble electric power but the idea of producing

appreciable amounts of power with living things is rather new

In 1961 Dr Frederick Sisler of the United States Geological Survey gave a demonstration of his biochemical fuel cell in which decomposing organic material from the ocean bottom produced electricity Sisler now is a vice president of General Scientific Corporation of New York and his firm has operated a radio transmitter powered by a bug battery over a distance of fifteen miles While the test biocells convert sea water to electricity—two volts of it—Sisler has also proposed using algae to convert sunlight into electric power

Scientists at General Scientific and also at Magna Products of California, feel that the potential in biopower is great The president of General Scientific Dr Robert Sarbacher, stated "this biocell introduces an era in which bacteria and other microorganisms may be harnessed to supply the power needs of entire communities Proponents of biopower feel that eventually such 'power plants may produce electricity at a cost of only one mill per kilowatt hour, making it competitive with nuclear and even conventional power plants With a maximum efficiency far greater than the heat engines operating today, the bug battery is surely one of the most intriguing possibilities on the horizon for solar energy

Man as Photochemist

Photosynthesis is only one example of the conversion and storage of solar energy Fortunately there are other simpler photochemical reactions Scientists list eight primary processes formation of free radicals, electron transfer intramolecular rearrangement photo isomerization, photoionization photoconduction in solids, photosensitized decomposition of unexcited molecules, and photophysical

processes such as fluorescence, phosphorescence, and so on

Not all these reactions appear feasible basic requirements for a practical photochemical reaction are that it be "endothermic"—that is absorb heat during the conversion process rather than give off heat—and that it be reversible Many demonstrated photochemical reactions are not reversible, many of them are all too quickly reversible A major problem is preventing this reversal until the stored energy is needed The following requirements enhance the attractiveness of the photochemical converter

1 The device must be cheap and easy to build
2 It must have low operating costs
3 Fuel produced must be easy to separate
4 This fuel must be capable of generating electricity efficiently
5 The device must convert a high percentage of the available solar energy into chemically stored energy

The two processes generally considered most likely to succeed in the economical conversion of solar energy are the formation of free radicals and the transfer of electrons In 1937, a big jump forward was made in photochemistry when the English biochemist, Robin Hill found that the chloroplasts in green plant cells evolve oxygen from water when illuminated in the presence of certain ferric compounds In the Hill reaction hydrogen and oxygen are separated when water is placed under ultraviolet light Krasnovsky in Russia achieved a similar reaction with chlorophyll extracted from the chloroplasts

Other researchers including Eugene Rabinowitch and Lawrence Heidt of Massachusetts Institute of Technology have demonstrated photochemical reactions of various types It has been shown that ferrous solutions when illuminated

have an electrical potential between the illuminated liquid and the dark portion This is in effect a battery that converts light to electricity somewhat like the semiconductor solar battery

Heidt worked with solutions which had the property of decomposing water into hydrogen and oxygen when illuminated by ultraviolet light While the reaction has been accomplished only on a laboratory scale, the idea is promising enough that designs have been made which couple Heidt s reaction with a fuel cell to produce electricity At the same time the hydrogen and oxygen would recombine and the water be re used for further photochemical conversion

Heidt refused to speculate on the possibilities of his photochemical reaction as a power converter for industry However he could foresee no reason for believing that the process could not become economically important Others have faith in the idea and much work has been done in this direction, with hydrogen suggested as a substitute for our present liquid fuels like gasoline and kerosene

To the uninitiated this may seem a mere laboratory curiosity until it is remembered that both oxygen and hydrogen are fuels, and that both are stable and storable Here in a sudden breakthrough was a potential way of converting sunlight not into electricity that must be used immediately or stored in a battery but into gaseous fuels which can be easily handled and stored or transported over great distances Of prime interest is the fact that one type of fuel cell is powered by oxygen and hydrogen So compatible are the two discoveries that a solar photolysis—fuel cell closed system has been proposed as a power plant for space flight In effect it would be fueled by water used over and over again and capable of storing energy for later use Sunlight breaks down the water into hydrogen and oxygen which are then —or later—recombined in the fuel cell to produce electricity

and water the latter being returned to the solar collector to be broken down again

Researchers at Oklahoma State University in 1962 presented a paper detailing their work on investigating the feasibility of energy storage by water electrolysis and high pressure storage of hydrogen The report suggests high-pressure tanks on automobiles which would use hydrogen to drive fairly conventional internal combustion engines Fuel-cell work is developing rapidly and tests have been made with farm equipment driven by electricity generated in the cells One happy byproduct of such work would surely be a lessening of the smog problem!

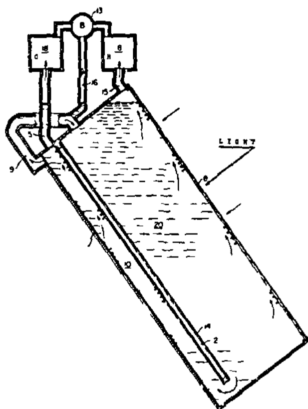
Although photochemical reaction thus far has resulted in the forming of only small amounts of fuel gas, feasibility of the idea has nevertheless been demonstrated Other laboratory work suggests a conversion efficiency for some photochemical processes of 60 per cent and higher, compared with the fraction of a per cent found in nature It would seem that the researchers are on a hot scent but much further work is in order to refine experiment to practice

More recent work has been done in photochemistry using other solutions Hydrogen peroxide nitrosyl chloride and a tongue twisting triphosphopyridine nucleotide—mercifully called TPN for short—are among these Experiments with nitrosyl chloride are especially promising with the reaction producing nitric oxide and chlorine Laboratory work at Stanford Research Institute uses a small solar furnace to provide the light necessary for the reaction and efficiencies as high as 1 7 per cent have been demonstrated

It has been suggested that a photogalvanic battery is a possible solar converter In this device sunlight would strike a colored solution containing electrodes Released electrons reach the electrodes and can be made to go through an external circuit Another type of solar battery using acridine

dyes and a reducing agent, potassium borohydride, charges in the light and discharges when placed in darkness

Two engineers working for the Boeing Company have pro-



Association for Applied Solar Energy

Photochemical use of solar energy to produce hy drogen and oxygen from water illuminated by light in the ultraviolet region

posed another type of photochemical solar converter Called a solar concentration cell the device would make use of the inversion of stereoisomers by ultraviolet radiation The

cell would have acid in each of its two sides, and light striking one would create an electrical potential between the two sides This could be used as generated or stored for later use Potential advantages for the concentration cell are its low cost as compared with silicon solar batteries, and the elimination of heavy storage batteries Further, it has a potential efficiency of 100 per cent since both conversion steps, solar-to-chemical and chemical-to-electrical, proceed at a theoretical ratio of one to one

Summary

Photochemical conversion is considered by some scientists to be of the greatest hope for man in the future By nearly all it is conceded to be one of the most difficult problems Fortunately many factors are working to the advantage of the photochemical process In the near future, space flight will require systems which photochemistry uniquely fits Photosynthesis for example may make possible planetary voyages of several years by providing not only food and power but also water, fresh air and the necessary waste disposal A photochemical system that separates water into its constituent gases in sunlight and recombines them in darkness to produce electricity is ideal for orbital flight in which part of the time is spent in darkness

Over the long haul, we earthlings must look to photochemistry including the photosynthesis of food and perhaps fuel to support our evergrowing and increasingly hungry population The prospect is optimistic As one scientist points out only a small amount of money has been spent on photochemical research for the promising results obtained The problems he concludes are human and not technical

9

The Users of Solar Energy

The present boom in space, both military and civilian has afforded solar energy the biggest opportunity of its long struggle Prior to 1958 the money spent on solar research and development was a tiny trickle but since then many millions of dollars mostly government money have been invested in harnessing sunlight

Historically the use of the sun is tied to the military beginning with the signal mirror in the inadvertent glinting of sunshine from the polished helmets or shields of soldiers In mythology the sun has often been called down to destroy and the solar mirrors of Archimedes represent the first military use of the sun as a weapon of destruction

However despite Hermann Oberth's warning of huge mirrors in orbit about the earth not only melting ice floes and warming fields for agriculture but razing whole cities as well the only practical military application of solar energy until World War II was the heliograph This solar signal

system definitely figured in British and American military operations

In World War II the sun was put to use to help save the lives of fliers downed at sea Coleridge s line about water, water, everywhere nor any drop to drink" was brought cruelly home You just can't drink salt water and survive As is often the case solar energy came to the fore in a remote" area without conventional means of providing fresh water *Dr Maria Telkes* invented plastic *stills small* enough to pack away in a survival kit, and yet big enough to convert about a pint of sea water a day into something drinkable In operation, the inflated plastic bag is placed on the water and a small amount of sea water poured in The sun raises the temperature inside the bag sufficiently to evaporate water from a 'wick, and fresh water condenses on the plastic surface The salt, of course, remains in the wick Periodically the fresh water is drained from the still and more salt water added

Thousands of these stills were produced during the war and they were standard equipment in life-raft kits More recently improved models have been developed, including one humorously called a 'sit still When the sun is not shining it can be warmed by being placed beneath the user like a cushion

Important as such an application is it represents only a tiny effort on the part of the military Much more impressive is the work done under military contracts in power conversion with solar energy The solar battery was developed by Bell Telephone Laboratories and first tested as an industrial or utility device but government agencies interested in space flight were not long in adopting it and other solar devices

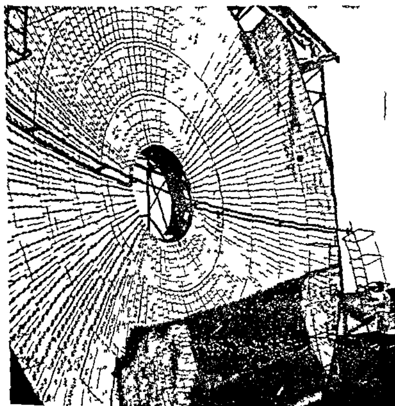
The steady rise of the efficiency of batteries stems at least in part from government contracts calling for basic

research on the problem The switch from p-n to n-p batteries for use in space was the result of Signal Corps investigations With their translation facilities government agencies are better able to keep up with foreign developments in the field the n p battery is an example, being a Russian idea

With its growing emphasis on space the Air Force is active in solar energy projects Small solar-powered radio transceivers have been developed for aviators survival kits The advantage is obvious Solar batteries can be stored for an indefinite time with no loss in power and when called on will continue to function indefinitely For high temperature research Air Force scientists investigated the solar furnace and at one time planned to build a giant 100 foot mirror in New Mexico We have discussed Air Force research into light communication methods for space use sponsoring work on the SOCOM system and also with a sun powered laser And while nobody is yet talking about an Oberth type death ray it is a safe bet that the government has investigated the possibility of the solar-powered laser as a space weapon The first plasma engine powered by solar energy was developed for the Air Force, it is a midget developing one hundredth of a pound of thrust At the other end of the scale is the fifteen kilowatt solar powered plant ordered from Sundstrand In addition the Air Force is underwriting continuing studies of solar batteries and other phases of solar energy application An example is work farmed out by the Cambridge Research Center of the Air Force to scientists in Israel

The Army too is interested in solar energy and has put it to good use in many applications It was Signal Corps people who produced the pioneer solar radio for Vanguard Work continues in solar battery research into radiation damage large area cells and so on On the ground the Signal Corps has used large solar panels to transmit radio messages

over long distances and smaller units in helmet radios for soldiers Lest our troops be fair-weather soldiers, chargeable storage batteries are added The Quartermaster Corps oper-



University of Wisconsin

Closeup of the 35 foot solar furnace at Mont Louis in southern France This is the world s largest such installation—note man on ladder

ates its twenty eight foot solar furnace for high temperature research and investigation of nuclear blast effects Actual testing of materials for use in such environments is accom plished as described in Chapter 7

The Navy is interested not only in solar stills but also the use of solar battery power supplies for buoys and other installations requiring a self-contained power supply One advantage of using solar power over possible nuclear packs is the safety factor This is an important consideration, as one buoy washed ashore in Nicaragua was hacked open with a machete by natives! Fortunately it was powered by chemical batteries

Telstar was hardly well established in orbit before it was announced that the Defense Department was interested in using it for military communications A system of such satellites would give the services dependable global communication and will undoubtedly be lobbed into the sky shortly

In 1877 an amazingly prophetic writer named Edward Everett Hale published a story called The Brick Moon This was actually an artificial satellite fired into space to be used for more accurate celestial navigation! The accuracy of the concept is demonstrated in government developed satellites sent aloft for the same reason Since the altitude and coordinates of such an artificial satellite can be calculated and set down in a list of tables navigators could shoot" them with a sextant in the same fashion as the natural celestial bodies The day may come when the flier, or the mariner, can look up and see landmarks in the sky and plot his position accurately and quickly without relying on radio accurate timing and so on A string of such satellites could lead a navigator in much the same way as the coded airways signal lights that crisscross the country now

As with many other scientific developments government underwriting eventually pays off for us all and not just in military security Radar was developed largely in World War II and work with it and with other electronic equipment undoubtedly hastened the advent of television for the civilian world While most of the billions spent in develop-

ing the atom bomb and the hydrogen bomb must so far be called military expense and experiment there are already some corollary benefits in medicine, industrial power generation, and other fields The same will be true of solar energy

Nonmilitary Government Work

Lest the foregoing make it seem that the government is exploiting solar energy only for its military worth, let us consider the National Aeronautics and Space Agency which is charged with most of our space programs NASA projects represent the bulk of current effort in space, and the government has actually been criticized for stressing nonmilitary work and the expenditure of billions of dollars for the apparent purpose of simply putting a man on the moon Bearing out the preponderance of nonmilitary applications, for every solar battery produced for the military in 1962, three went to nonmilitary projects

NASA s many laboratories support a variety of solar energy programs Dozens of vehicles mounting solar batteries have been launched, and another two dozen or so are scheduled for the near future NASA scientists point out that solar energy is with nuclear energy, the only functioning power plant in space, and that this will continue to be the case for several years yet

Practically every NASA space vehicle launched is fitted with solar panels many of them using thousands of solar batteries each In addition work is supported on other types of power plants such as the thermal mechanical Sunflower, and a solar thermionic Mars vehicle power plant NASA is sponsoring development of ion and plasma space engines also powered by solar energy

Apart from the space effort the government is interested in other solar programs The largest by far is the development of solar stills for conversion of sea water, sponsored by the Department of the Interior s Office of Saline Water With water covering most of the earth s surface we are not faced with a shortage of H_2O But as both population and per capita use of water increase we already have areas in which fresh water is in critically short supply

Solar still research parallels the work carried out with stills fueled by conventional means and thus far capital costs of sun powered stills have not been low enough to make them economically competitive with oil fired stills However as improved methods and materials become available solar scientists are hopeful of a breakthrough that will produce fresh water at a cost less than one dollar per thousand gallons

The Department of Agriculture is interested in solar energy too and conducts research and testing The Bureau of Mines and the National Bureau of Standards have also been involved in solar energy work

Our foreign aid programs have furnished solar powered listening centers' to be tested in undeveloped areas of South America and Asia The International Cooperation Administration is behind the listening center idea AID has also tried to bring the blessings of solar energy to backward areas though its programs have met some obstacles The solar powered boat for use on the Amazon is an example

One phase of solar energy research—that of studying the sun itself—historically has had an easier time of it The government sponsors programs like those of the High Altitude Observatory in Denver New Mexico s Sacramento Peak Observatory and the newly completed Kitt Peak facility in Arizona—the largest such installation in the world The huge Kitt Peak telescope will give an image of twice the

size of earlier telescopes and permit studies not previously possible

These important studies and the pioneering efforts of men like Langley and Abbot, aided by the Smithsonian In-



Association for Applied Solar Energy

A Somor solar powered pump produced in Italy for use in irrigation The large collector panels follow the sun for greater efficiency

stitution and other government agencies are the basis for successful applications of solar energy

Industry

Government alone cannot carry on the development of the science of solar energy and many private firms are in-

vesting their own money in such work The Association for Applied Solar Energy lists many industrial firms among its membership There are dozens of manufacturers producing solar devices or the materials for them

Bell Telephone Laboratories invented the solar battery, and a number of firms have been licensed by Bell to manufacture the batteries among them Hoffman Electronics Corporation, International Rectifier Corporation, Heliotek, and several others Hoffman and International Rectifier both market solar radios and the latter firm produces electrical kits featuring solar batteries

J W Fecker Company has built a number of solar furnaces including the Quartermaster Corps twenty eight foot mirror, and many others for industry Dupont has developed more efficient and more durable lightweight plastics for solar energy applications Corning Glass Works and the American St Gobain Corporation are among those working to develop solar house heating RCA, GE, and Westinghouse are working on the conversion of solar energy to electricity

On a modest scale, small manufacturers are producing solar reflector cookers for use by campers picnickers, or in the backyard And some novelties and toys like cigarette lighters and radiometers are being turned out

While home heating has not progressed past the test stage, solar water heaters are big business in Florida and in several foreign countries Solar pool heaters too are finding acceptance and are being produced commercially A recent solar application is the plastic tepee or Wig Warm Invented by the young daughters of solar home builder A W Thomason the Wig Warm is light and easily portable and offers warm comfort for campers hunters and others during winter days

Institutions

Scientific groups have done much to advance the state of the solar energy art. Among these is the American Rocket Society, whose members would hardly seem interested in use of the sun's energy. Although it seems akin to treason, rocket authorities suggest using solar plants for auxiliary power and even for the propulsion of the coming space vehicles.

The use of solar energy is simply the use of heat in many applications, and it is natural that thermodynamicists and others practicing in industry are interested in the sun and its potential. The American Society of Mechanical Engineers has a subcommittee on solar energy and many of its members are active in the new field.

Because of the great potential for solar energy in their fields, the American Society of Heating, Refrigeration and Air Conditioning Engineers and the American Institute of Architects are also interested and active.

It was not until 1954 that solar science got its own society. In that year the Association for Applied Solar Energy was formed in Phoenix, Arizona. The AFASE was formed by a group of academic, industrial, financial and agricultural leaders in the Southwest to stimulate research leading toward greater utilization of solar energy. The location in the Valley of the Sun, scene of solar experiments half a century before, was a fitting choice. Henry B. Sargent was the Association's first president.

Stanford Research Institute and the University of Arizona helped the infant organization find its footing, and in 1955 the AFASE organized the first World Symposium on Applied Solar Energy. Lewis W. Douglas was chairman and Merritt Kastens of Stanford was vice chairman, with an ad

visory committee including scientists Charles Abbot of the Smithsonian Institution, Vannevar Bush Godfrey L Cabot Dr Maria Telkes of New York University, Frank Lloyd Wright, and other leading solar scientists

Registering for the conference in Tucson and the symposium in Phoenix were 900 representatives of the sciences, education, government, industry, and finance In addition to scientists from the United States there were delegates from 36 countries who came to present papers and to demonstrate their projects at the solar engineering exhibit This high spot of the symposium showed more than 80 solar devices ranging from cookers and steam engines to radios powered by the solar batteries invented only a year earlier

Coming as it did on the threshold of space use of solar energy, the AFASE World Symposium set the stage for the new era of solar energy In the years since, the sponsoring organization has weathered the storms of growth and continued to function as a clearinghouse of information on solar energy work around the world It has sponsored other conferences and symposia, including one in 1958 for youthful scientists has built a solar heated home and introduced two publications which detail progress in the solar field The Sun at Work and the Journal of Solar Energy Also published have been authoritative volumes on solar research

Brigadier General Harold Walmsley ret is now the president of AFASE. The organization is located at the Arizona State University and has its offices on campus at Tempe Carrying out the original international aims of the association international secretaries have been appointed in Russia England Chile India Australia Japan Italy and Canada A formal international branch has recently been formed for Australia and New Zealand Five recently elected councilors are Dr Freddy Ba Hli of the Union of Burma Applied Research Institute Dr Athan D Hatzikakidis of the Hellenic Scientific Society of Solar and Aeolian

Energy, Greece, Dr Mostafa M Hafez, National Research Center of Egypt, Dr Julio Hirschman, Universidad Tecnica Frederico Santa Maria, Chile, and Dr Gerald T Ward of Brace Research Institute, McGill University, Canada

Present membership in AFASE numbers 670, in 41 states and 52 foreign countries It includes scientists, engineers, industrialists, educators and students, with the last-mentioned entitled to reduced membership and dues AFASE is aided financially by the National Science Foundation

Many research organizations throughout the country are involved with solar energy projects Among these are Stanford Research Institute, Battelle Memorial Institute Arthur D Little, Inc, National Research Corporation Franklin Institute, Bjorksten Research Laboratories, Eppley Foundation for Research, General Motors Research Laboratories Charles F Kettering Foundation, Mellon Institute of Industrial Research, Minneapolis-Honeywell Research Center and Yellott Solar Energy Laboratory

Colleges and universities are active in solar research programs, and on some campuses special courses are given pertaining directly to solar energy The following listing while not complete, is representative

Arizona State University and University of Arizona both have been active in such work and at the latter institution a solar laboratory has been heated and cooled with solar energy

University of California s Department of Agricultural Engineering has done work with solar heated farm buildings and pools At Berkeley the school s radiation laboratory investigated organic dye solar batteries which would be cheaper than silicon and the College of Engineering worked with solar stills and power systems utilizing the difference of temperature in the ocean which, of course is a form of solar energy

The University of Florida under direction of Dr Erich

Farber has an active solar energy program and has done much work on behalf of heating and ventilating engineers

Massachusetts Institute of Technology has developed solar house heating over a long period of time and also re searched many phases of photochemistry

Michigan State University s Agricultural Engineering De partment has conducted studies of solar energy availability collection and storage for farm use In progress are studies of roof orientation for best solar energy exposure and the design of solar air heaters

Minnesota University s Department of Mechanical Engi neering has worked on the design of solar collectors and the utilization of solar energy for drying

New Mexico Institute of Mining and Technology in vestigated the use of solar furnaces and solar pumps

New York University s College of Engineering Research has studied solar heat collectors low cost distillation meth ods and the use of solar furnaces in high temperature coat ings

Purdue University s Agricultural Engineering Department has worked on solar-powered fence chargers and solar re frigeration of livestock shelters

The University of Wisconsin has long been interested in solar energy and its applications and special projects there include work with the design of solar cookers and their testing in the field absorption cooling solar stills and energy storage methods Dr Farrington Daniels of Wiscon sin is one of the world s authorities on solar energy and co author of the book *Solar Energy Research*

Around the World with the Sun

The United Nations has long been interested in the de-velopment of solar energy particularly with respect to

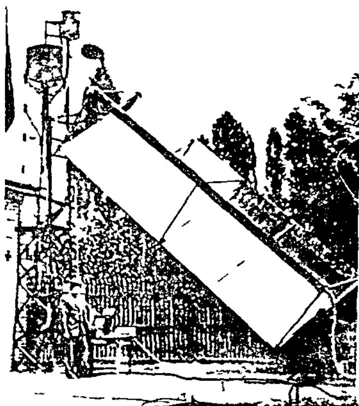
applications in the under-developed lands of the world In 1961 the UN sponsored the United Nations Conference on New Sources of Energy in Rome Representatives of some sixty countries were on hand to hear papers by specialists in thirty countries on the use of solar energy, wind power, and geothermal power Solar energy was the main event of the conference and of particular interest was the revolutionary Battelle Institute Stirling cycle solar engine, and the five-horsepower solar-powered turbine NATO, too has concerned itself with solar energy, and in 1961 cosponsored a conference held in Greece

Since the solar belt extends completely around the world solar research and development is of course not limited to the United States Russia for example, is very active in the field As part of the space program Russian solar battery work is highly advanced While the United States invented the device Soviet scientists were first to use the n p type which we quickly adopted for its much greater protection against radiation

Originated in 1950 the Heliotechnical Laboratory has turned out precision reflectors used for welding and cookers used by the hundreds the equivalent of a 600 watt hotplate One clever device is a solar boiler that folds up compactly into a suitcase Water heaters of all sizes have been developed and are used not only in Tashkent but in Ashkabad and Tbsili as well The most ambitious is a large heater at Tashkent which boils 500 liters of water daily In the capital of Uzbekistan a solar boiler is used to produce 130 kilograms—about 300 pounds—of ice And at the laboratory in Tashkent another ice making machine produces 350 kilograms in a day

The Russians have designed a large solar boiler to be built in Soviet Armenia This plant would produce two and a half million kilowatt hours per year but since it would require

some five *acres* of mirrors to reflect sunlight onto the boiler it is doubtful if anything more than a pilot plant will ever be built



Association for Applied Solar Energy

This large reflector heats tubes to generate steam in Russian solar power plant

While progress with large rural power installations remains slow Soviet scientists are moving faster with the newer and more sophisticated conversion techniques For example using a six foot mirror to focus heat onto a semi

conductor thermoelectric generator, they claim to have produced one horsepower

It was the Soviet scientist Abram Ioffe who sparked the recent revival of thermoelectricity, and Russia built solar-powered thermoelectric converters many years ago Dr V A Baum has guided Soviet research as director of the Solar Energy Laboratory of the Power Institute of the U S S R Academy of Sciences

The Japanese are also active proponents of solar energy The Kobayasi Institute of Physical Research at Tokyo and the Government Industrial Research Institute at Nagoya are two centers of such activity Since Japan is a leader in electronics production and her scientists have invented such advanced semiconductor devices as the revolutionary tunnel diode, it is not surprising to find production of solar batteries among their accomplishments These are put to practical use in remote radio installations and in lighthouses where they function for long periods with little maintenance The Japanese people love baths and in Japan the solar water heater is mass produced More of them are used there than in the rest of the world combined By 1960 there were 250-000 in use and an annual saving in coal of one ton per heater is estimated by the Japanese The heaters range in price from nine to eighty dollars

Solar cookers are produced in a variety of shapes and there are industrial and research solar furnaces in operation A more unusual solar energy application is in the production of algae in plastic tanks The Japanese critically short of food have done more work in this direction than any other country and long ago produced *chlorella* food supplement powders commercially An acre of pond area produces about twelve tons of algae yearly

Other research and development projects range from the use of solar heat to distill sugar cane juice to the heating

and cooling of residences One clever invention combines the inflatable life preserver with a solar still'

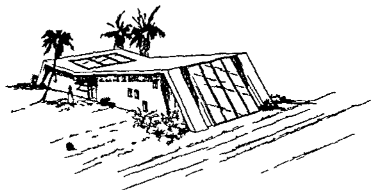
United States scientists feel that Israel is doing some of the most interesting and productive work in the solar en ergy field Headed by Dr Harry Tabor workers at the National Physical Laboratory of Israel have produced five-horsepower turbines ' fueled by inflated plastic reflectors, highly efficient heat absorbers for use in heaters and power plants using solar energy and a promising idea called the solar pond ' in which a large pond is treated chemically to store the heat of the sun then covered with plastic After a certain period the heat stored in the water is used to power a steam engine Since this type of energy collection and storage is cheap and simple it is felt that there are great possibilities for the solar pond idea

At the Israel Institute of Technology Nathan Robinson has developed water heaters coolers stills and driers The leading solar energy product of Israel is the Miromit solar water heater a unit so efficient that the country s electric utilities have been forced to drop their prices to compete with the sun This is perhaps the first time that solar energy has been economically competitive with conventional power on earth and thus marks a big breakthrough in the tech nology The heaters are being produced at the rate of four thousand a year and sold in Israel and four other countries

The Israeli scientists are doing work for the Cambridge Research Center of the United States Air Force on selec tive surface heat absorbers Dr Tabor and his colleagues have developed the most efficient blackened collectors known for trapping solar heat These surfaces have a high *absorption but a low emissivity and thus hold from 80 to 90* per cent of the heat striking them

Under the leadership of Dr Felix Trombe France continues to honor its proud heritage of solar energy leadership

The big thirty-five foot solar furnace at Mont Louis remains the largest in the world, and surely the most active and productive, since it operates continually both for research and industrial smelting Not resting on his laurels, Trombe has begun a truly huge furnace at Odeillo This giant will use a mirror 115 feet by 165 feet, which will actually form



Association for Applied Solar Energy

Artist s drawing of solar heated house built in Casablanca by the Association for Applied Solar Energy Hot water is also furnished by the sun

the side of a laboratory building The Odeillo furnace will have an output of 1,000 kilowatts making it the first solar installation in the megawatt or million-watt range

Algeria is active in solar energy research perhaps as a defensive gesture since much of her territory lies in the Sahara Desert One logical aim is the air conditioning of desert houses using solar heat But Algerian scientists have done much more sophisticated work The third largest solar

furnace in the world is situated at Bouzareah It has been used for photochemical research and for nitrogen from the atmosphere Also under study are thermoelectricity photoelectricity, selective surfaces, and solar batteries Radiosol water heaters are produced commercially

Burma is fortunate in having one of the most aggressive of the solar scientists Dr Freddy Ba Hli has built low-cost cookers heaters and stills and experimented with use of solar energy in salting fish Now he feels that a solar-powered refrigerator would be of more value to his people than a cooker

Canada has built at least one solar heated house, despite its far north location In search of warmer climate McGill University has opened the Brace Experiment Station in Barbados West Indies to do solar research

Ceylon sweltering in the heat is researching the use of solar energy for refrigeration Also, in 1955 scientists there performed a service to the world by measuring solar radiation during an eclipse

Chile was the scene of large solar stills in the last century, and engineers are again proposing such installations Currently the sun is being put to use only in evaporating pits for chemical companies but research is being done on heaters, cookers furnaces and solar batteries

Like the Japanese the Chinese are active in the solar energy field This applies to both Nationalist China and Communist China On Taiwan the population has doubled since 1946 and estimates are that local fuel resources will last only another forty years at present rate of consumption Therefore work is being done at Taiwan Normal University to produce cookers space heaters water heaters and furnaces for island use to save conventional fuels

On the mainland it is reported that about eighty Red Chinese factories mostly in Shanghai are turning out heat-

ers and cookers This work began in 1958 and has been so successful that solar energy is now used in food preparation, distillation sterilizing, water pumping shower room installations ovens and driers

It was in Egypt back in 1913 that Shuman and Boys set up the world s largest solar steam plant rated at one hundred horsepower Today scientists there are investigating sea water distillation solar heating drying baking pumping, and so on

England though quite far north has done a fair amount of solar research Many of its scientists are pessimistic about the possibilities, but Professor Harold Heywood has been quite active, and worked with Theodor Finkelstein on the early models of the revolutionary hot air engine described elsewhere in this book

Germany has a few exponents of solar energy Dr J H Dannies has been active in solar heating, cooling, drying, and even extracting drinking water from the air with solar energy As early as 1935 he built a solar refrigerator, and recently tested improved designs in the Negeb Desert in Israel Friedrich Tonne is interested in proper use of the sun architecturally Some algae culture research has also been done

India has excellent solar scientists in Dr M L Khanna and others and has developed practical solar cookers stills and heaters The problem has been that Indians either don't have the money to buy them or won t take time to learn how to use them With the National Physical Laboratory at New Delhi as headquarters current work is going forward on solar refrigerators and solar power plants for villages

Solar research is conducted in Iraq at the Al Hikman University and Baghdad University

Italy host to the United Nations conference in 1961, has built water heaters and space heaters among other projects

Residential installations of water heaters have been made
The University of Bani is a research center
In Lebanon Adnan Tarcici perfected a collapsible solar



Association for Applied Solar Energy

Solar cooker designed for use in India

cooker A onetime United Nations delegate Tarcici patented his cooker in the United States

Down under in New Zealand and Australia much solar work is being done as the formation of the AFASE branch

for that area would indicate The most recent development is the installation of a 12 foot solar furnace on the Kensington Campus of the University of New South Wales The furnace develops about 5 kilowatts of heat and has reached temperatures hotter than 3,300° K Production of salt from the sea water is another solar energy application and experiments are being made with spraying the brine through the air to speed evaporation The World Power Conference held in Melbourne in 1962 featured many papers on solar energy

South Africa has done continuing research on space heating water heating, stills and solar furnaces

In Spain there is a Special Energy Commission which carries out work in solar energy research

Outside of cheese making there is only about one thing the Swiss could use solar energy for and they have done just that The Advanced Research Division of Patek Philippe Company produces and markets solar powered clocks

Whether they subscribed to Galileo or Ptolemy the ancients had to admit that somehow the sun got around It still does and its blessings fall on everyone except perhaps the penguins and Eskimos Not all of us have oil or nuclear materials not all of us have fertile soil or fresh water But we all have sunshine, the single common denominator with which we face the future and its certain shortages of many kinds We can beg borrow or steal almost everything else but sunshine doesn t lend itself to such appropriation Thus the sun may well be the great equalizer that will one day break down the barrier between the have s and the have not s It was with great wisdom that the Lord said Let there be light

10

Old Sol A History

One of the truest truisms ever uttered is that which says there is nothing new under the sun The expression itself dates far back to some of the earliest writings including the Old Testament There are many biblical references to the sun including that in the 19th Psalm

The Heavens are telling the glory of God

In them He has set a tent for the sun
Which comes forth like a bridegroom leaving his chamber
And like a strong man runs its course with joy

Its rising from the end of the heavens
And its circuit to the end of them
And there is nothing hid from its heat

The sun naturally figures in man s earliest attempts to probe the world around him So obviously were we children of the sun that early religion and culture were built around that celestial body Ra the sun god and his Heliopolis are well known in ancient Egyptian lore Greek and Roman

legend continued this idea in Apollo and Phaeton with the sun itself a fiery chariot driven across the face of the sky Druids and Aztecs, oceans removed, worshiped the sun Around the world, then and down through the ages man has lifted his eyes to the sun First with awe and fear that prompted human and other sacrifices to the god in the sky, and more recently with complacent gratitude and even curiosity

In 1875 Padre Angelo Sechi's book, *The Sun*, commented on man s attitude toward that body

> Several peoples of antiquity worshipped the Sun, an error perhaps less degrading than many other since this star is the most perfect image of the Divine the instrument whereby the Creator communicates almost all his blessings in the physical sphere

The sun has been both blessing and challenge as far back as Icarus and Daedalus who dared fly too near the sun and perished Somewhere along the line myth and legend begin to give way to fact Surely temple fires were lighted, and doors swung open, by sunlight, but something more impressive happened in 212 B C the year in which the great Greek thinker Archimedes is supposed to have set fire to the fleet of Marcellus, the Roman when it attacked Syracuse

De Temperamentis is the earliest writing to mention this scientific feat of Archimedes With burning glasses, says Galen, ' he fired the ships of the enemies off Syracuse Historians Livy and Plutarch make no mention of this use of solar energy, though they do note other highly sophisticated weaponry devised by Archimedes to fight off Marcellus Unfortunately the Roman laid siege to Syracuse and in the end he captured it and had Archimedes killed

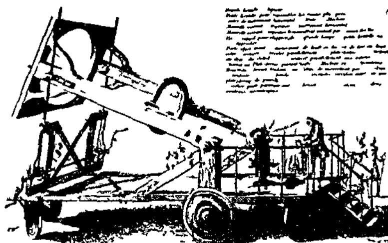
It remained for twelfth century author Joannis Tzetzae

By the seventeenth century, the science of lens making was advancing rapidly In 1695 two Italians named Targioni and Averoni used a large burning glass to decompose a diamond undoubtedly an experiment that taxed their budget Other researchers using burning lenses at the time were Parker in England and Tschirnhauss in Germany The duke of Orleans bought two of Tschirnhauss lenses measuring thirty three inches in diameter and these were used by French scientists Among the work they did unfortunately was proving the validity of the phlogiston theory then current that heat was a material substance

In the late eighteenth century the French scientist Lavoisier finally undid the erroneous work of his predecessors and disproved the faulty phlogiston theory using powerful lenses to focus sunlight and burn samples In these experiments he clearly showed that there was no weight lost or gained and that the element phlogiston was therefore not real Lavoisier used curved glass discs fastened together at their rims with wine filling the space between The vintages used are not identified but we do know that Lavoisier was furnished glass by the great St Gobain glassworks This same firm provides the mirrors used in France s Mont Louis solar furnace and the American St Gobain Corporation has worked with Dr George Lof in this country on the glass collectors for his solar heated home Using a large 52 inch lens and a secondary 8 inch lens Lavoisier achieved a temperature close to 1 750° C and almost succeeded in melting platinum This was far beyond any temperature attained by man until that time

Lavoisier also carried the science of the solar furnace forward by heating samples in vacuum and in controlled atmospheres by using quartz containers He also noted that the fire of ordinary furnaces seems less pure than that of the sun a very important consideration as later researchers

have brought out It was Lavoisier's misfortune to live during the Revolution, and his fate to die on the guillotine because "the Republic had no need for scientists" With the lopping off of this pioneer s head work with solar furnaces died too and it was more than a hundred years before men



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Solar furnace built by Lavoisier for high temperature research Lenses A and B were hollow glass shells filled with wine The cautious scientist is wearing dark goggles

again sought elevated temperatures using optics ana the sun s rays

Power from the Sun

We have mentioned de Caux and his primitive solar engine that used hot air to pump water While it would be many years before a more sophisticated solar fired hot air engine would be developed hot air engines in general are interesting historically Almost ten years before James Watt

patented his steam engine, Henry Wood obtained a patent on a hot air engine A patent and a working model are not the same thing however, and it was not until 1807 that Sir George Cayley successfully operated one

In 1816 the Scottish clergyman, Robert Stirling, and his brother, James built a two-piston air engine Although it was not designed to be operated by the sun, the Stirling cycle has as previously mentioned, proved ideally suited for such use

John Ericsson introduced his hot air engine in 1826, and saw 300 horsepower versions of it power the paddlewheeler *Ericsson* Later it was to be adapted for solar operation

A number of inventors began working on solar engines at about the same time August Mouchot, with the backing of Napoleon III developed a steam engine powered by the sun, in the period from 1866 to 1872 This effort was exhibited in Tours and later tested in Algeria for pumping water Six years later, Mouchot produced a larger version with an improved boiler arrangement This was tested for six months in a water distillation plant, but the government decided Mouchot s engines could not be made with an economy sufficient to the demands of commerce

Swedish inventor John Ericsson had meantime come to the United States and was famous during the Civil War for his Monitor Ericsson had built many successful hot air engines and it was not surprising that he turned his inventive mind to using the big fire hot enough to work engines at a distance of 90 million miles In 1868 his work in this direction had earned him an honorary Ph D from the University of Lund in his native land

Ericsson claimed his solar engine 'operated by the intervention of atmospheric air" was the first of its kind and also that his earlier solar steam engine held the same distinction These solar engines may be seen in the American Swedish

Historical Society in Philadelphia By 1875 Ericsson had built eight different models of his solar engines, but while he claimed high efficiency for the designs none of them was practical In 1883 he made one last try, building what was the second biggest solar engine of that day Measuring 11 by 16 feet, the rectangular parabolic collector drove a piston with a 6 inch bore and 8-inch stroke Designed to work with steam or air, the engine was connected to a 5-inch pump and Ericsson claimed it delivered one horsepower for each hundred feet of collector, or close to two horsepower with the collector he used

Discouraged with the immediate economic prospects of solar energy as a competitive fuel, even though he felt "the field waiting it is almost beyond computation," Ericsson cleverly converted his solar engines to run on coal or gas and dried his eyes on the way to the bank More than 50,000 Ericsson hot air engines were sold all over the world, repaying the inventor several times for the expense of his solar research

In 1876 shortly before Ericsson built his big solar engine, a man named Adams put together an amazing forerunner of today s huge solar engines Built in Bombay, this 2½-horsepower steam engine was heated by a huge hemisphere formed of 10- by 17 inch mirrors, a collector measuring 40 feet from edge to edge[1] This solar giant was used as a pump

In France about 1880 Abel Pifre built the first solar engine used in a commercial venture His steam engine fired by a 100 square foot parabolic collector, generated two-thirds horsepower and Pifre put it to work running a print ing press The paper understandably was called *Le Journal Soleil*

Shortly after this achievement another Frenchman Charles Albert Tellier built a solar engine that was unique in more ways than one Instead of using a focusing collector

as had all his predecessors except perhaps de Caux Tellier used a "flat plate" type. Its 215 square feet of area drove an engine with ammonia as a working medium instead of steam, air or water. An illustration in the Scientific American in 1895 shows such a system in which the flat plate collector serves also as the roof of a factory building, an intelligent attempt to cut costs of the installation.

Time and again men proved that there was power in sunshine and put it to work. But all were ahead of their time and the ideas did not take hold. As Ericsson sadly lamented, although solar energy was free, capital investment was so high for the necessary collector and associated equipment that it cost much more to run a solar engine than a conventional type.

Solar Cookery

The sun as a cooking device is ancient too. Foods have been sun dried for ages. But the development of the solar cooker dates back only some hundred and fifty years. Adams in Bombay, Herschel in England, de Saussure in Switzerland and Mouchot in France pioneered the field building simple "ovens" with glass lids to let in the sunlight and trap heat inside. Mouchot demonstrated his cooker effectively at the World Exhibition in Paris in 1878, cooking a pound of beef in a little over twenty minutes. Samuel Pierpont Langley, whose solar research is honored in the "langley" as a unit of solar radiation, built such a cooker and demonstrated its use atop Mt. Whitney. Dr. Charles Greely Abbot built a more sophisticated oven in 1916 and tested it for several years on Mt. Wilson.

Through the ages man has exploited one manifestation of solar energy—the evaporation of water by the sun. The ancients harvested salt and the practice is carried out today in

much the same manner except for some refinement in the way the product is gathered and handled There is of course a byproduct to the production of this salt—that of fresh water In some areas this commodity is in critical supply, and in 1871 a huge solar still was built by an American named Charles Wilson in Las Salinas, Chile, to provide a mine with drinkable water Another such still was operated at the Oficina Domeyko mine The Las Salinas still provided 6 000 gallons of water a day and operated successfully for forty years, yet today there is little on the spot to mark the location of this pioneering use of solar energy Indeed the method had been forgotten and had to be reinvented some time ago by French engineers who won a prize offered by their government for a means of providing fresh water from salt or brackish supplies

Threshold The Twentieth Century

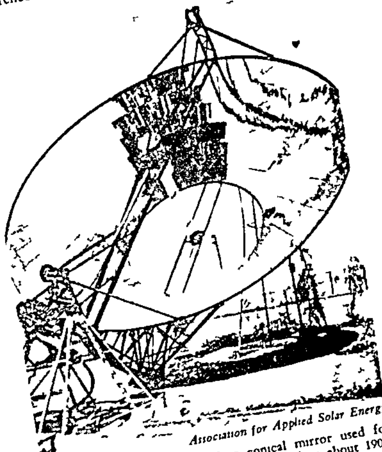
Just before the turn of the century, there was a reawakening of interest in the United States and a number of fairly large solar engines made their appearance One was installed at the Pasadena, California ostrich farm to pump water The thirty-three foot apparatus is attributed to A G Eneas and a band of Boston capitalists' who apparently did not have their heads in the sand Later, these designers moved to a location where the solar engine had much appeal, the desert land of the Arizona territory

The Arizona Republican, a Phoenix newspaper, carried this description of the strange device in its issue of February 14 1901

> The unique feature of the solar motor is that it uses the heat of the sun to produce steam As no fuel is cheaper than any fuel the saving to be effected by this device is evident When the solar rays have heated the water in the boiler so as to pro

duce steam the remainder of the process is the familiar operation of compound engine and centrifugal pump

The reflector somewhat resembles a huge umbrella open



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Solar steam engine with 35 foot conical mirror used for pumping water at an ostrich farm in Pasadena about 1900 Gear arrangement in left foreground permitted mirror to follow sun

and inverted at such an angle as to receive the full effect of the sun s rays on 1 788 little mirrors lining its inside surface The boiler which is thirteen feet and six inches long is just where

the handle of the umbrella ought to be This boiler is the focal point where the reflection of the sun is concentrated If you reach a long pole up to the boiler it instantly begins to smoke and in a few seconds is aflame From the boiler a flexible metallic pipe runs to the engine house near at hand The reflector is thirty three and a half feet in diameter at the top and fifteen feet at the bottom On the whole its appearance is rather stately and graceful and the glittering mirrors and shining boiler make it decidedly brilliant

In the morning the machine is thrown into focus by a few turns of a hand crank In about an hour the gauge in the engine house indicates 150 pounds of steam pressure The engine may then be started and allowed to run all day without attention A clockwork arrangement keeps the reflector following the sun around automatically the engine is self oiling the water passes back from the condenser to the boiler so that the latter is always full The present model runs a ten horse engine and lifts 1 400 gallons per minute equal to 155 miner s inches, twelve feet from an underground tank

It is expected that under the nearly vertical rays of the summer sun the present model will develop from fifteen to twenty horsepower But this is by no means the limit since several reflectors may readily be grouped about a central engine and made to produce 100 horsepower and perhaps much more The solar motor is simply the cheapest possible means of producing steam because it saves all expenditure for fuel and labor It is available for use wherever steam power is needed It can be used to generate electricity and the power then stored in electric batteries Other and cheaper means of storage may be devised in time Any attempt to predict possibilities in this field would be mere guesswork but it is safe to say that solar power will be one of the great influences of the new century and will make the arid regions of the west and other parts of the world the theater of the greatest industrial revolution of the future

Eneas holder of a patent on the solar engine, and a number of backers operated it at several locations and apparently successfully pumped irrigation water A price of $2,500 to

$3 000 was quoted for the solar devices but alas for the bright dreams of inventors, promoters, and editorial writers, the solar engines fizzled out for a variety of reasons Mechanical troubles and accidents plagued the installations, and a wind storm finally destroyed one completely

Amid rumors that an engine had been sold to a European concern and a larger one ordered for Egypt, there was desultory interest in solar power in the desert country for a few years In 1907 a promoter named Albert Carter was still pushing shares of stock in the Solar Furnace and Power Company $2 per share now, next year it may be $10, or maybe $15 or $20! ' Carter even had a model engine on display It was not a steam boiler type like that of Eneas, but the old faithful hot-air engine fired by a large collector mounted on a track to follow the sun

Desirable features claimed for Carter s engine beyond the fact that it ran on nothing but sunshine and air were that it couldn t blow up or explode, and that a ten year old boy could run it!'' Prices started at about $650 for a five horsepower plant But buyers seemed to have decided that the whole thing was hot air, or perhaps it was just so hot in Arizona that no one was interested in an engine anyhow At any rate only very recently has there been any more mention of solar engines making the desert around Phoenix bloom as the rose

Independent of the ostrich farm capitalists two men with their own ideas for solar engines began experiments in 1902 with the flat plate collector that Tellier had introduced in France H E Willsie and John Boyle Jr built their early engines in Olney Illinois and St Louis Missouri In these engines heat was trapped in water flowing through shallow glass covered basins and used to drive water ammonia engines Such a collector was obviously cheaper to build than the complicated mirror types that followed the sun

By 1905 Willsie and Boyle headed for the land of sunshine and set up shop in Needles, California, a town then featuring sand, solar energy, and little else Using about 600 square feet of collector area they operated a slide-valve engine that ran a water pump, a compressor, and two circulating pumps In 1908 a second and larger plant was built at Needles This one had 1,000 feet of collector area and could store heat for later use The solar heat generated a boiler pressure of 215 pounds and drove a sulphur-dioxide engine claimed to develop about 15 horsepower Estimated cost of construction for the plant was $164 per horsepower, still about four times the cost of a conventional steam plant But sunshine, after all, was free

Kilowatts for Cairo

About 1907, in Tacony, Pennsylvania, an inventive engineer named Frank Shuman was beginning a career as the solar energy missionary who came closest to making the grade A hardheaded realist, he espoused the economical flat plate collector idea used by Willsie and Boyle His test engine had 1 200 feet of collector area and produced a creditable 3½ horsepower Emboldened by success, he proposed not an engine but a huge solar steam plant that would cover four acres! To cut costs the collector would be simply the tract of land itself rolled level and formed into shallow troughs A layer of asphalt waterproofed the trough which was then filled with about three inches of water Over this, Shuman proposed to pour a thin film of paraffin, apparently to help trap heat in the water The whole area would then be covered with glass leaving a six-inch air space between glass and water This monumental project would store heat so that low pressure turbines could be run con

been worked out and show it would have paid off in three years

But good an engineer as he was, even Frank Shuman wasn t good enough to make solar energy stick Eastern Sun Power Company, Ltd, had been formed to provide power for irrigation from the Nile, a job traditionally done by some 100,000 *fellaheen*, or Egyptian laborers Caught in an advance skirmish of the battle of automation versus manual labor, plus economics and the confusion of World War I Shuman's marvelous solar power plant was abandoned and fell into disrepair It must have crushed the inventor, surely it laid the entire solar energy field low for a long time

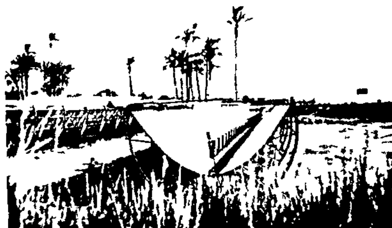
Dark Years

In the years that followed, scattered reports of solar applications made the news and kept the idea alive In New Mexico an engineer named Harrington lighted a mine in a remote area with electricity produced by solar energy in a novel fashion During the hours of sunlight a concentrator focused the sun s rays onto a boiler whose steam drove a pump to lift water to a storage tank some distance above ground Water falling from the tank drove a dynamo to provide around the clock power output

Dr Abbot persevered with his solar work both research into the radiation of the sun and applications of this energy He received a number of patents for his cookers and boilers, models of which are now on display in the Smithsonian Institution His designs are the only indirect cookers in which the cooking unit can be removed some distance from the solar collector This means that cooking could be done inside the home instead of in the backyard an important

consideration Abbot also encouraged another solar energy enthusiast in his work

In 1919 a scientist doing research and development in another field made mention of the use of solar energy as an aid to that work Dr R H Goddard who would one day be saluted belatedly as the father of modern rocketry published a modest paper called 'A Means for Reaching Ex-



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Two of the huge reflectors in the Shuman Boys 100-horsepower solar engine built in Egypt and tested in 1912 The reflectors automatically tracked the sun

treme Altitudes' This means of course, was with chemical rockets, but in his paper Goddard touched on the use of solar energy to aid in getting a rocket to the moon

In 1924 Goddard filed for a patent for an 'Accumulator for Radiant Energy" By 1930 he had applied for a total of five patents pertaining to solar energy and his solar power plant described in detailed drawings in 1929 looks for all the world like the practical designs being built today for

use in space Goddard wisely knew that the storage of heat was an important part of the solar engine and his patents covered efficient means for doing this Present day cavity flux traps look like Goddard s early designs and his use of a quartz window for permitting sunlight to enter directly into the chamber of his vaporizer anticipates the work of Battelle Memorial Institute scientists and their improved Stirling cycle solar engine

Claiming an efficiency of 50 per cent for his solar power plant Goddard foresaw tremendous possibilities for solar energy particularly on farms Moving up from the earth he envisioned solar powered aircraft—the fuel was weightless he said—and even space travel accomplished with sun energy An interesting proposal was a solar powered dirigible To get around the high weight of a large metal mirror Goddard cleverly proposed a thin layer of light fabric coated with highly polished metal foil This was amazingly close to a description of the aluminized plastic presently being used for that very job

As early as 1907 Goddard had hinted at solar energy for electrostatic space propulsion[1] Again in 1911 he discussed the use of solar energy in space travel It is a remarkable coincidence that the man who pioneered the rockets that are now blazing trails into space should also concern himself with solar energy And it is unfortunate he did not live to see the two streams of science converge that day in 1958 when the Vanguard I blasted off with the first solar batteries aboard

Dr Abbot by now the dean of the science continued his work patiently with solar applications and by 1936 had produced a solar steam engine which produced one half horsepower This engine was exhibited at the International Power Conference in Washington and caused a flurry of interest particularly when it furnished the power for a nationwide radio broadcast

In his definitive book on the sun, Italian physicist Georgio Abetti mentions his countryman Antonio Pacinotti ex pounding as early as 1870 on various sophisticated solar energy utilization projects These ideas included using the sun to decompose chemicals for driving gas engines build ing heat absorbing pipe systems for the Sahara Desert and exploiting the difference in temperature of deep sea waters Even this last idea has been investigated and shows promise

From 1925 to 1935 the French scientist Georges Claude better known for his work with acetylene, conducted experiments in tapping sea thermal energy In this period Claude spent a fortune of his own money installing and testing a submarine cold water pipe from a power station off the coast of Cuba and a vertical pipe from the floating *Tunisia* power station He was successful in operating a steam turbine on the temperature difference from top to bottom of the ocean but performance was disappointing The French government has carried on his work and in 1948 formed ***Energie des Mers*** for continued sea thermal research, more recently other groups have proposed similar schemes

Even the generation of electric power from sunlight has a long heritage Way back in the dim past of electricity in 1822, Thomas Johann Seebeck discovered that a magnetic needle held near a circuit made up of two different con ducting materials was deflected when he heated one part of the circuit We have seen that Seebeck misread what he had discovered and refused to think of the effect as electrical and not magnetic For a hundred lost years the thermoelectric Seebeck effect was a laboratory freak unused for any practical purpose Even when Jean Charles Peltier discov ered that he could reverse the Seebeck effect and create heat by passing a current through a particular circuit and even make cold by reversing the direction of current flow no one tumbled to the idea of making electricity from heat It was

not until the 1930s that Abram Ioffe in Russia began to make progress with thermoelectricity and even coupled solar collectors with his generators to produce electricity from sunshine

The photovoltaic solar battery too has a long history and one almost as misunderstood as that of thermoelectricity In 1839 Antoine Becquerel found that sunlight caused a weak current in certain materials in this case the electrodes of an electrolyte solution Forty years later Adams and Day observed a similar effect in a solid material, selenium The exposure meter using selenium cells and electric eye' applications were the main uses of photovoltaic conversion with the converted electricity too feeble for anything except making a needle move on a scale or activating a switch in a control operation

In 1931 Dr Bruno Lange demonstrated photovoltaic solar power at Kaiser Wilhelm Institute His invention was a sandwich of copper oxide, silver selenide and a third, secret ingredient Exposed to sunlight the battery powered a small electric motor indefinitely Professor Colin Fink of Columbia University developed a similar power converter in 1935 This device consisted of layers of copper and copper oxide

But despite the fact that semiconductors were known even to Seebeck far earlier it was not until 1954 when Bell announced its revolutionary silicon solar battery that solar electricity really came of age

Where the Sun Now Stands

We know the sun itself has been around a long time but it comes as a surprise to realize that men have been trying for so long to harness its energy There have been many factors against an early victory even when some pioneers

must have felt they had it surely in their grasp First was a lack of knowledge, and when men acquired knowledge they still were short of the technology to apply it Most frustrating of all must have been the apathetic lack of interest by their fellow men in this bounty from the sun The onetime abundance of cheap' fuel whipped solar energy in the marketplace But the sun is patient, it has time More time than does man as that individual is beginning to rea'ize Solar energy science will progress faster now Maybe one day we will pay a little belated homage to those who helped it along its first faltering steps

11

The Coming Age of Solar Energy

In the preceding chapters we have se
that solar energy despite a long heritage and a present fair
active and healthy life is still an infant with regard to applications What can we tell of its future and how do such a prediction tie in with a prediction of man s future i general? A wise man has said that we cannot envision fifty years hence simply by multiplying the last twenty five years by two or even by multiplying the present year by fifty The conditions that prevail now obviously will not at the turn of the next century so we can make only wise guesses as to population power needs and environmental conditions Speaking strictly of solar energy and its probabilities then we cannot make clear cut extrapolations to arrive at future performance Just because the solar battery has improved from 4 per cent to 14 per cent in about ten years for example we cannot intelligently predict a like 10 per cent jump in the next ten Nor can we say it will increase 3½

times or 14 divided by 4 Ten years hence it may remain at 14 per cent It may drop to 5 per cent because of degradation by man made radiation from atom bombs or it may jump to 50 per cent through the use of new techniques or some startling breakthrough rivaling the original invention We can only set some end points, knowing that these are far in excess of what may be achieved but at least they represent a limit beyond which we cannot go The dream of successfully garnering *all* the energy in sunlight—a continuous one-and-one-third horsepower per square yard of area—is a dream only Even a tenth could make us all rich with respect to power

We may, of course, have no need of any more solar energy than what nature doles out in her own sweet time Nuclear power may solve this worry for us by reducing our present three billions to a tiny fraction of that most of whom will huddle in caves and forget about electric power for ages However being optimistic—or pessimistic depending on our views—we may look for as many as eight billion human beings on earth in another century This is what is meant by population explosion a teeming increase that some say will have each of us standing in a square foot of area in three hundred years unless something is done Perhaps man will become even more prolific for one reason or another and there will be sixteen billion The eight billion figure is based on a growth of about 4 per cent a year and is felt to be as realistic an estimate as is possible in the atomic age

Even with the qualifications we make on predicting actual values we realize that 8 billion people are going to need more energy than 3 billion of us now do When Columbus first came to America there were only a few hundred thousand red men here But even this relative handful as compared with our present population density had saturated the land It was not capable of supporting any more lives with

the low efficiency methods the Indians had at their command We will pass over the question of whether that many pastoral and contented beings are not better off than 170-000,000 harried and hurried ones Whatever is is even if it is not necessarily right

Generally, a higher yield of food or fuel per acre requires the expenditure of more energy And standard of living appears to depend on available power With much of the world s three billion population in danger of starving today we realize that eight billion will require a much more mechanized way of life barely to stay alive Rather than a two- or three fold increase of energy needed, the factor will in all probability be much more than that Proof of the difficulty of assigning exact numbers lies in the estimates now made by experts One says that our eight billion souls will be using twenty times the power we use today Another says fifty times

We talk of one world in various tones some of us wistfully some scoffingly But in nature we always see a tendency to equalize to level off Temperatures and pressures try to stabilize at one point rather than remaining at different levels This is the case also with human beings and their demands for power particularly as the world is shrunk drastically by increasing world trade communications and social and cultural mingling One writer has deplored the sucking of Eskimo pies by Balinese dancers during intermission, but such are the facts of life Whether or not Coca-Cola does anything uplifting for us has nothing to do with its wide acceptance all over the world And the wants of the have nots extend past candy and soft drinks to television and refrigeration to home lighting and mechanized travel

Although the United States uses half the world s total power and produces half the goods and services it may surprise and embarrass us in the United States that we are not

the most conspicuous individual consumers of power That honor goes to Norway, with a yearly per capita use of power of about 6 800 kilowatt hours Canada rates second with 5,400 and the United States is third with 4 500 But compare these figures with those at the other end of the scale Some Asians use a skimpy 27 kilowatt hours per person less than half of 1 per cent as much as the Norwegians! An earlier chapter pointed out that the power richest third of us uses about 85 per cent of earth s total power And the poorest sixth uses only 1 per cent With the present accent on aiding undeveloped countries we should be concerned about helping others bring up their power standards Whether we are concerned or not it will gradually come about Such a leveling would jump the need for power in the world by a factor that starts at seven and goes on up, depending on which expert you choose to consult

What does this have to do with solar energy? If the world needs more power surely the coal operators oil companies and electric utilities will be happy to oblige them the more the merrier at so much a kilowatt hour Unfortunately this is not the case There is only so much coal to be dug and that s all The same holds for oil This ' capital energy is limited and it is not being replaced fast enough to be of any help whatever Old Mother Nature has provided us with a handy stockpile of energy, but she has done so at a terribly low efficiency rate and over a considerable span of years We don t have those millions of years to wait around for coal and oil and natural gas to be replaced

How much do we have left at present? Estimates vary but one set of figures gives us about 27 Q one Q as we know being 30 billion tons of coal This is a pessimistic outlook according to other authorities and with known and expected reserves they estimate as much as 200 Q in the bank At a recent scientific conference one speaker reported

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We talk of one world in various tones, some of us wistfully some scoffingly But in nature we always see a tendency to equalize to level off Temperatures and pressures try to stabilize at one point rather than remaining at different levels This is the case also with human beings and their demands for power particularly as the world is shrunk drastically by increasing world trade communications and social and cultural mingling One writer has deplored the sucking of Eskimo pies by Balinese dancers during intermission, but such are the facts of life Whether or not Coca Cola does anything uplifting for us has nothing to do with its wide acceptance all over the world And the wants of the have not s extend past candy and soft drinks to television and refrigeration to home lighting and mechanized travel

Although the United States uses half the world s total power and produces half the goods and services it may surprise and embarrass us in the United States that we are not

the most conspicuous individual consumers of power That honor goes to Norway with a yearly per capita use of power of about 6 800 kilowatt hours Canada rates second with 5,400 and the United States is third with 4 500 But compare these figures with those at the other end of the scale Some Asians use a skimpy 27 kilowatt-hours per person less than half of 1 per cent as much as the Norwegians! An earlier chapter pointed out that the power-richest third of us uses about 85 per cent of earth s total power And the poorest sixth uses only 1 per cent With the present accent on aiding undeveloped countries, we should be concerned about helping others bring up their power standards Whether we are concerned or not, it will gradually come about Such a leveling would jump the need for power in the world by a factor that starts at seven and goes on up depending on which expert you choose to consult

What does this have to do with solar energy? If the world needs more power, surely the coal operators oil companies and electric utilities will be happy to oblige them the more the merrier at so much a kilowatt-hour Unfortunately this is not the case There is only so much coal to be dug and that s all The same holds for oil This capital energy is limited and it is not being replaced fast enough to be of any help whatever Old Mother Nature has provided us with a handy stockpile of energy, but she has done so at a terribly low efficiency rate and over a considerable span of years We don t have those millions of years to wait around for coal and oil and natural gas to be replaced

How much do we have left at present? Estimates vary but one set of figures gives us about 27 Q one Q as we know being 30 billion tons of coal This is a pessimistic outlook according to other authorities and with known and expected reserves they estimate as much as 200 Q in the bank At a recent scientific conference one speaker reported

that there was little to fear since for the next *century* at least he foresaw no shortage of electric power! This takes care of the next three generations perhaps we owe no more to posterity

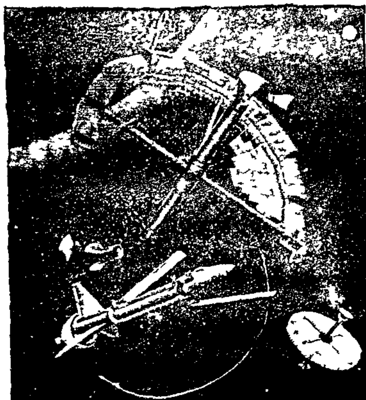
Of importance is the fact that while there *is* still fossil fuel left we have already gone through the cream—if we may shift metaphors—and are now working on the skimmed milk with the bottom of the bottle embarrassingly visible Surely there is more coal and surely there is more oil We just have to dig deeper or haul farther or process more But it takes energy to mine a ton of coal and when that energy approaches what is contained in the coal itself we are in trouble and had better leave the stuff in the ground where at least it will prevent a cave in

Help from the Atom

Malthus stuck his neck out a few hundred years back and predicted that mankind was running into a mathematical barrier against further growth He based his gloomy forecast on the fact that population was increasing algebraically while food production was fixed to an arithmetic scale Theoretically he was right but technology stepped in and produced food more efficiently to break the population barrier Today many point to the discovery of atomic power as a similar timely and providential intervention Certainly the power of the atom has been proved in bombs and there is some progress in converting that destructive power into useful power for industry But there is a fly in the ointment again Just as coal and oil are limited so are the atomic materials They are also difficult to process and as the supply dwindles they become more so

Reserves of uranium and thorium used in atomic piles for

the production of heat which can be converted to electricity are estimated variously at from 50 to 175 years Proponents of atomic energy, however, were severely jolted to hear



American Bosch Arma Corporation

Artist's concept of the construction of a solar powered space station Entire structure forms collecting mirror to focus heat onto power plant (Frank Tinsley drawing)

that perhaps there may not be enough suitable radioactive isotope material to make atomic power plants, even in small sizes, for space use The fact that there is uranium in the amount of a few grams in each ton of granite is questionable

good news Granted that this tiny amount will give a power equal to 50 tons of coal how many tons of coal may be required to extract the grams from the ton of granite?

There is the possibility of fusion power The power of the hydrogen bomb a small scale copy of the sun as a matter of fact far outstrips that of the old fashioned fission bomb The hydrogen bomb is even more devastating than the atom bomb and when and if harnessed, its power may well be of great use for industrial and utility power production But there are problems Nuclear physics has been accurately if unkindly called 'unclear' physics For one thing it is easier to make bombs than to generate power constructively One reason for this is that the fusion of hydrogen takes place at about 100 million degrees Centigrade and may be just too hot to handle

Many billions of dollars have been spent on atomic and nuclear development Although industrial power is being produced today it is not fair to say that it is economical as yet considering the development costs Fusion power generators though promising theoretically have so far been discouraging as to actual results A breeder reactor takes a fair amount of its own power to run itself Fusion may do the same Even optimistic forecasts do not mention practical production of fusion power for the next twenty five years

Even if fusion were to be perfected in a year or so and go into large scale production of power, it would still not solve once and for all the matter of energy requirements Although some starry eyed rooters for fusion claim that sea water would be a limitless reservoir for the heavy water needed other more sober proponents feel that there is sufficient deuterium only for some five hundred years Couple this news with the estimate of a fifty fold increase in power consumption in the next century and even fusion power is seen to be limited Certainly with space travel a

reality the expenditure of fuel can be expected to rise ever more steeply A grimmer prospect is nuclear war, or even 'conventional war, fast using up stockpiles of fuel that are irreplaceable

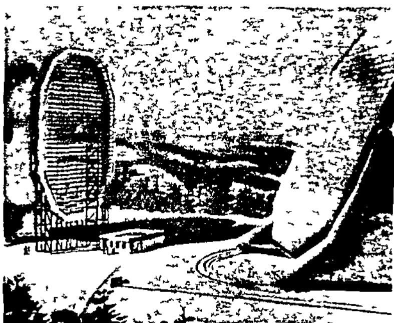
Besides these disadvantages of the nuclear fuels there are the more familiar dangers Even though industrial plants hopefully will produce no widespread fallout there is the possibility of accidental blowup Personnel working nearby would be constantly exposed to danger, and there is the ever-present problem of what to do with radioactive waste Even burying it in the sea or firing it out into space are not final answers We might succeed in contaminating both those reaches killing off plant and animal life and making space travel even more dangerous Disposal in space is particularly questionable First, such expensive garbage trucks would be wasteful of fuel And there would be the possibility that the stuff might not go into orbit and come down on us as fallout instead

Another, and for this discussion final drawback of the at first glance so promising atomic fuels is the fact that they are geared to huge installations Nobody is advocating a pocket-sized nuclear power plant for shipment to a backward village in Africa or Asia The nature of the beast suggests it will be a multimegawatt operation and tied to power lines which waste an appreciable part of the power sent through them

Summing up nuclear and atomic fuels are dangerous costly and most important they too are exhaustible Even if the optimists are right and there is fuel for one thousand more years, what happens then? If we look at the problem with some detachment we realize that future generations may well wonder why man spent so much time and effort exploiting indirect power before turning—as he must eventually—to the surest source of supply the sun itself

Where Do We Go from Here?

It has been estimated that today man is using about 2 per cent direct energy, that amount of his power comes from the sun in the form of wind water or through the burning



Association for Applied Solar Energy

Proposed 100 foot solar furnace The heliostat on the right follows the sun and reflects its rays to curved mirror at left

of wood and other quickly replaced carbohydrates Use of solar energy directly, as with solar batteries in a satellite, or as power for a furnace represents only a tiny fraction of the total There are many reasons why we can t switch to sun energy overnight Yet one authority suggests that within a hundred years direct solar energy *must* make up 40 per cent

of the total supply Starting from a standstill then, how do we begin to put solar energy to work?

The man who can buy a gallon of kerosene for a quarter and burn a million calories out of it isn t too interested in building a solar collector that won t be nearly as handy to use and may take ten years to pay itself off Solar energy, at its present state of development can't often compete with cheap fuel Profit for the power utilities in this field is decades off, and perhaps large cities can never be adequately served by direct solar energy alone

We have mentioned the importance of the boost given solar energy by the space effort Until this happened the amount of money spent in research was pathetic, even a modest bill for ten million dollars had never been favorably acted on by Congress So the space effort amounting to millions yearly for solar energy, is a great shot in the arm Just as government sponsoring of the diesel engine and war development of radar and atom bombs have eventually filtered down to the general public in the form of transportation, television, and benefits to cancer patients so space race solar developments will one day pay off for earth as well

The advance of solar energy will be two pronged, however It is attractive in the exotic field of space exploration mainly because no other source of power is available the spaceship can t pull up to a filling station and refuel There aren t many filling stations in the undeveloped areas of earth, either and few electric power plants It is here that a wedge may shortly be driven with small power packages like those of Dr Tabor and his co-workers in Israel and others around the world

After the conference on new sources of energy held in Rome during August 1961, the United Nations made this report on the affair held under its auspices

One of the most significant suggestions coming out of the Conference concerned the establishment of pilot centers and experimental stations in less-developed, energy poor states which are, however favored with plentiful wind and sunshine These stations or centers would serve several purposes They could undertake such tasks as distribution of solar and wind measuring instruments supervision of their use dissemination of information about site selection and equipment adaptation of equipment to local needs and generally contributing to clarification and solution of technological problems under actual conditions of operation The projects would also enable an increased exchange of research workers

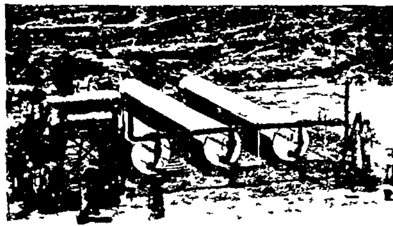
The pilot stations would be more than technical centers They would be in a position to demonstrate possibilities of savings and to act as intermediaries for technical and financial aid and be path breakers for actual application under conditions prevailing in less developed areas by providing a better understanding of the social and economic problems connected with introduction and maintenance of these new energy applications ranging from solar cookers to ice making machines pumping and other power operations at the level of individual households and the village

Building a nuclear plant is a vast undertaking presupposing strict government control and the expenditure of millions of dollars But the sun shines everywhere and as yet no one owns it There are no do-it yourself atomic energy projects—or so let us fervently hope—but by its nature solar energy is available to any hobbyist in his own backyard To build a power line may cost several thousand dollars a mile, but a native in Asia or Africa or South America with an acre of land could set up a solar engine of a few horsepower and take care of all his needs A village could do the same thing

One authority feels that solar energy will serve another purpose too—that of bridging the mental gap between us and

those peoples with no way of comprehending the complexities of the civilized atomic world Closer to nature than we, they should more readily accept solar energy applications and move at least a small step toward meeting us on common ground

Scientists in India are making detailed studies of rural life, and the power needs of such people Solar cookers are an actuality if disappointingly few in number Windmills are



National Physical Laboratory of Israel

The Tabor 5 horsepower solar plant being assembled in Jerusalem Cylindrical elements collect heat to drive turbine

a distinct probability in areas of steady winds and solar engines seem to be the answer for small scale pumping water heating electricity and even refrigeration It has been mentioned that this last may be of even more importance than heating in villages which now must waste scarce food for lack of ability to store it

The Chilean solar still that functioned for forty years was perhaps the most practical use of solar energy to date To-

day the sun is being put to work in evaporating ponds for the production of salt in Chile Special dyes are used to achieve more efficient use of solar heat, and appreciable quantities of oil are being saved Scientists in that country have proposed a modern solar plant which will produce 4 500 gallons of fresh water a day, and also 50 kilowatts of electrical power Along with production of the water will go the reclamation of salt and other minerals which will make for more efficiency in the solar plant The investment cost is estimated at about $200 000 about $4 000 per kilowatt This is about ten times that of a conventional plant but it should be remembered that the cost of shipping fuel to the high regions of Chile would be exorbitant and also that the water produced enhances the value of the project

Bountiful as the sun is we may feel some pinches in the process of learning to live on our income of solar energy A L A Reynhart of Velsen, the Netherlands points out some interesting things about a society subsisting entirely on solar energy He sees man squeezed for the most part into a narrowed 'solar belt between the thirty degree parallels north and south Food sufficient only for a population density about twice that of Japan today will be available world wide and this would feed only four billion people—far short of the expected six to eight billion

Reynhart goes on to show that since much of the earth is water man will be hard put to produce sufficient food and power for himself even with solar collectors and engines of 10 per cent efficiency He points out that man may have to decentralize and suggests learning more about nature s process of photosynthesis This recalls the suggestion that if nature could more efficiently convert the energy received by an acre of ground the crops would amount to about three *tons a day* Work with chlorella artificially grown and with added amounts of carbon dioxide has boosted the ton

nage to some twenty tons a year but we are a long way from three tons a day

Challenge from the Sea

There is a clue in the statement that most of the sunlight falls on the sea rather than on land Many authorities have long insisted that we must exploit the sea and its fish and vegetation if future generations are to eat well The same philosophy has been adopted by some power experts Solar thermal energy (STE) is a challenging prospect of utilizing solar energy It has a long if so far not highly encouraging history We have seen that Claude spent huge sums of his own money in a project off Cuba and with the floating station *Tunisia* to generate power from the heat of ocean water Through his experiments and follow up projects by the French government the feasibility of the idea had been proved The French might have put such a plant into operation off the African Gold Coast except for the bringing in of cheaper hydroelectric power to the area

The advantages of such a solar energy application should be apparent First it operates around the clock so that there is no problem of storage of energy Second it draws on a vast area provided by the ocean itself and saves the expense of an artificial collector Such an economically attractive scheme may someday boom the semitropical countries as industrial sites

Asa E Synder, vice president and research director of Pratt & Whitney Company, Inc points out that STE offers some 370 *trillion* dollars yearly in equivalent energy within the ' thermal-difference belt of 20 degrees north and south latitudes This is about the same as 131 billion tons of coal or more than 4 Q of energy and far more than the total consumption of the entire world

Another sea thermal energy proposal is to float large flat plate collectors on the ocean and heat quantities of water to a high temperature Then the difference between the heated water and normal sea water would be used to operate a solar engine

Work going on in Israel on the so called ' power pond has been described One scientist has proposed such a solar plant with one square mile of area Covered ingeniously with one piece of plastic, this huge heated pond would deliver 92 million kilowatt hours per year at a cost of less than half-a-cent a kilowatt hour

An even more imaginative solar energy application has been suggested for the Libyan Desert Wasteland below the level of the sea would be reached by tunneling through higher ground, and filled with sea water through this tunnel Evaporation would then constantly lower the level of this artificial lake and thus draw water through the pipes and this moving water would be tapped for hydroelectricity[1] A roundabout method to be sure but solar energy nonetheless And with electricity in that area selling for 8 cents a kilowatt hour, and water at $14 per 1,000 gallons solar energy would be not only attractive but competitive

Dr Farrington Daniels has suggested the creating of power or storable fuels using nothing but solar heat and the atmosphere available in the deserts of the world In the first step water would be extracted from the air using absorbers and solar heat The water would then be broken down into hydrogen and oxygen again by solar energy and these gaseous fuels could be recombined in a fuel cell to make electricity or burned to produce heat or power An alternative plan would also reclaim nitrogen from the atmosphere with a solar furnace and mix the nitrogen with hydrogen to produce ammonia which could be easily transported as a fuel

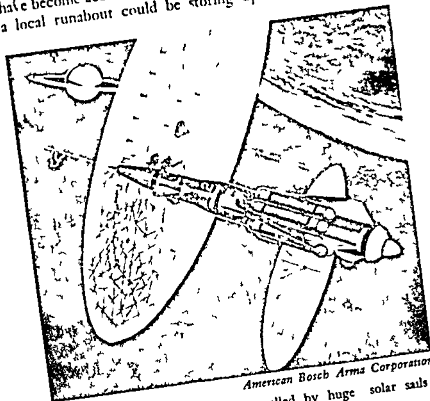
Similar schemes for use on land include those in which tall vertical wind machines utilize the energy from solar-heated air rushing through them Here again the need for expensive light reflecting collectors is obviated The shape of the solar energy engine of the future then, may not be anything like the polished reflectors or glass hot-boxes that have thus far taken the eye of the solar researcher While the solar roof of semiconductor material may well take care of domestic needs large industries may not be able to afford miles of collectors in the desert and will resort to ideas analogous to the heat pump, draining the energy from huge volumes of air

Perhaps the most breathtaking solar energy concept yet is that of Russian Nobel prize winner, Nikolai Semonov, who envisions a fantastic powerhouse in the sky in which the moon is covered with semiconducting material to convert sunlight into electricity which is somehow transmitted back to earth!

Conclusion

The exact shape and form of future solar energy engines is not known But we do know with some assurance that they must one day be used, and perhaps the sooner the better The space race has provided the initial impetus, and development of backward areas should keep the ball rolling The first real use of solar energy in the energy rich nations will in all probability be for air-conditioning Space heating represents a big 25 per cent of our total fuel needs, and the sun can do this job very efficiently We can even add refrigeration to heating and save ourselves much more electricity or gas Rural electrification and perhaps eventually independent power supplies for individual homes even in the city may come next

It has been pointed out that we could not carry around a collector big enough to power an automobile in the style we have become accustomed to This is a bit shortsighted since a local runabout could be storing up electricity all day



American Bosch Arma Corporation

Artist s concept of spaceships propelled by huge solar sails (Frank Tinsley drawing)

against the hour or o we would need it Beyond that there is no reason why cars fueled by hydrogen oxygen fuel cells or even hydrogen fired internal combustion engines, cannot operate And the sun can provide us with such gaseous fuels

Man since the time of James Watt, has found himself in the position of a farmer who has never learned how to

grow things but merely goes to a cave and unearths tins of food put up by someone else long ago If nature had not left us a legacy of coal and oil, we would today be drawing energy full time from the sun Dr Valentin Baum, of Russia s Heliotechnical Laboratory makes an interesting comment on the situation

Just imagine for a moment that mankind had based his power industry on solar radiation not fuel and then the proposal to use different kinds of fuel was put forward Probably there would have been very many objections One could imagine that one of the most important arguments in defense of solar energy would be formulated as follows Solar radiation is a noble form of energy and it was under its influence that life originated and continues to develop on Earth therefore its use no matter on what scale could represent no danger or inconvenience for either the flora or fauna of the world The use of any other kind of fuel would inevitably be connected with the poisoning of the atmosphere water and land Fuel should be used only where there are no other possibilities of obtaining energy, and in the sunny regions of the world the energy of the Sun should be used

The sun s radiation here on earth is not like another kind of radiation we have become painfully aware of lately Neither does the sun give off the noxious fumes that cause horrors like the four thousand deaths in London in 1952 The sun brings life and not death

It may well be a blessing that man is at last being forced to make use of solar energy directly And as we stand on the threshold of the age of solar energy, a new age of plenty made possible by this most noble form of energy, how fortunate it is that none are hid from his heat

Index

Daniel S Halacy Jr, was born in Charleston South Carolina, and attended high school in San Diego, California He graduated from Phoenix College and Arizona State University He first worked in air conditioning later in the aircraft field During World War II and the Korean War he served in the Air Force becoming a first lieutenant with thirty-one missions as navigator and radar observer in B 29 s He spent ten years with Convair helping to build prototype PBY amphibians and doing work on the Atlas missile He has done technical writing for A Research and Goodyear and published several books and many stories and articles Since 1956 Mr Halacy has taught at Phoenix Evening College and he now has a tele course on KPHO TV